Regulatory Affairs
8330 Century Park Ct. CP32F
San Diego, CA 92123-1530

February 28, 2019

Edward Randolph
Energy Division Director
California Public Utilities Commission
505 Van Ness Avenue
San Francisco, CA 94102-3298

RE: SAN DIEGO GAS & ELECTRIC COMPANY'S (U 902 E) 2018 ELECTRIC PROGRAM INVESTMENT CHARGE ANNUAL REPORT

Dear Mr. Randolph:

In compliance with Ordering Paragraph 16 of Decision (D.) 12-05-037 and in accordance with the Annual Report Outline provided in Attachment 5 of D.13-11-025, San Diego Gas & Electric Company (SDG&E) hereby submits its 2018 Annual Report for its Electric Program Investment Charge (EPIC) Program (Report), provided as Attachment A hereto. In addition, SDG&E provides the excel file titled "SDG&E 2018 EPIC Project Status Report" in accordance with D.13-11-025 as Attachment B,[1] and its EPIC Final Reports as Attachment C.[2] Together, these documents provide an overview of SDG&E's EPIC activities and program financial information during the 2018 calendar year.

SDG&E and its fellow EPIC Administrators are required to each submit an annual report "detailing program activities."[3] The annual reports are designed "to facilitate consistent reporting by the [EPIC] Administrators on their investment plans and project results."[4] In accordance with D.12-05-037, SDG&E serves this Report on "all parties in the most recent EPIC proceeding, and all

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[1] SDG&E, the California Energy Commission (CEC), Pacific Gas and Electric Company (PG&E), and Southern California Edison Company (SCE) (together, the EPIC Administrators) are required to provide with the annual report "electronically in spreadsheet format the information identified in Attachment 6 to report on projects described in Section 4.b of the EPIC annual report outline adopted by this decision." D.13-11-025 at 63. *Id*. at Attachment 5 and Attachment 6.

[2] The EPIC Administrators "must include with their [EPIC] annual report a final report on every project completed during the previous year." D.13-11-025 at 136, Ordering Paragraph 14. Due to size, Attachment C is being made available to all parties via Notice of Availability.

[3] D.12-05-037 at 8.

[4] D.13-11-025 at 4-5, 62.

parties to the most recent general rate cases for [SDG&E, PG&E, and SCE], and each successful and unsuccessful applicant for an EPIC funding award" through December 31, 2018.[5]

Sincerely,

/s/ SDG&E Regulatory Affairs

cc: SDG&E Central Files

[5] *Id*. at Ordering Paragraph 16.

ATTACHMENT A

SDG&E 2018 EPIC ANNUAL REPORT

San Diego Gas & Electric Company
2018 EPIC Annual Report

February 28, 2019

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APPENDICES

I. EXECUTIVE SUMMARY

Pursuant to Ordering Paragraph 16 of Decision (D.) 12-05-037 and in accordance with the Annual Report outline provided in Attachment 5 of D.13-11-025, San Diego Gas & Electric Company (SDG&E) hereby submits its 2018 EPIC Annual Report (Report). This Report provides an overview of SDG&E's EPIC activities during the 2018 calendar year. As required by D.13-11-025, SDG&E is providing additional information about SDG&E's EPIC activities in an excel file titled, "SDG&E 2018 EPIC Project Status Report" as Attachment B, and its EPIC Final Reports as Attachment C.[1]

SDG&E proposed and received approval for five projects that demonstrate smart grid system integration solutions in its first triennial application for years 2012-2014 (EPIC-1).[2] In addition, SDG&E proposed and received approval for six projects that demonstrate grid modernization and technology integration solutions in its second triennial application for years 2015-2017 (EPIC-2).[3] This Report provides an update on SDG&E's 2018 progress and year-end status for projects approved for both EPIC-1 and EPIC-2.

A. Overview of Programs/Plan Highlights

In A.12-11-002, SDG&E requested Commission approval of five programs that demonstrate smart grid system integration solutions. In November 2013, SDG&E's Application and First Triennial EPIC Plan was approved in full, with minor modifications, by the Commission in D.13-11-025. The total SDG&E budget for the first triennial cycle is $8,600k. Ten percent of this amount ($860k) is allotted to program administration. The remainder ($7,740k) is allotted to technical work in the Technology Demonstration and Deployment (TD&D) programs, which are limited to pre-commercial demonstrations.

In A.14-05-004, SDG&E requested Commission approval of its Second Triennial EPIC Plan which included five programs that have the potential to help modernize the utility power system to improve customer benefits, as well as a sixth project through which SDG&E will

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[1] D.13-11-025 at 63 and 136.

[2] Application (A.) 12-11-002, which was approved by the California Public Utilities Commission (Commission) in D.13-11-025. SDG&E's Application (A.17-05-009) for its third triennial application for years 2018-2020 (EPIC-3) was approved by the Commission in D.18-10-052, issued November 2, 2018. Progress on EPIC-3 projects will be addressed in SDG&E's 2019 Annual Report.

[3] A.14-05-004, which was approved by D.15-04-020.

participate in industry RD&D consortia. In April 2015, SDG&E's Application and Second Triennial EPIC Plan was approved in full, with minor modifications, by the Commission in D.15-04-020. The initial total committed SDG&E budget for the second triennial cycle was $8,679k. Ten percent of the total authorized budget of $8,792 ($879k) was allotted to program administration. The remainder of the committed budget ($7,800) was allotted to technical work in TD&D projects, which are limited to pre-commercial demonstrations. Subsequently, some of the administrative funds were moved into project work as permitted by EPIC rules.

B. Status of EPIC-1 and EPIC-2 Projects

As discussed in further detail below, throughout 2018, SDG&E completed the remaining two modules of EPIC-1, Project 2. The final reports for these two modules are provided with this annual report (*see* Appendices 1 and 2). All other EPIC-1 and EPIC-2 projects were completed in 2017 and reported on in the last annual report.

SDG&E's updated portfolio for both EPIC-1 and EPIC-2 is provided in Table 1 below.

Table 1. SDG&E's EPIC-1 and EPIC-2 Portfolio as of December 31, 2018

EPIC-1 Projects (2012 – 2014)				
EPIC Project	**Incurred[4] Costs ($ thousands)**	**Encumbered[5] Costs ($ thousands)**	**Commitments[6] ($ thousands)**	**Project Status**
1. Smart Grid Architecture Demonstrations	1,406	1,406	1,406	Complete
2. Visualization and Situational Awareness Demonstrations	2,212	2,075	2,301	In Progress
3. Distributed Control for Smart Grids	1,392	1,392	1,392	Complete
4. Demonstration of Grid Support Functions of Distributed Energy Resources	1,201	1,200	1,200	Complete
5. Smart Distribution Circuits Demonstrations	1,441	1,441	1,441	Complete
6. SDG&E Program Administration	826	746	860	In Progress
Total	**$8,478**	**$8,260**	**$8,600**	

EPIC-2 Projects (2015 – 2017)				
EPIC Project	**Incurred Costs ($ thousands)**	**Encumbered Costs ($ thousands)**	**Commitments ($ thousands)**	**Project Status**
1. Modernization of Distribution System & Integration of Distributed Generation and Storage	2,032	2,009	2,009	Complete
2. Data Analytics in Support of Advanced Planning and System Operations	1,098	1,111	1,111	Complete
3. Monitoring, Communications, and Control Infrastructure for Power System Modernization	1,305	1,305	1,305	Complete
4. System Operations Development and Advancement	1,088	1,088	1,088	Complete
5. Integration of Customer Systems into Electric Utility Infrastructure	985	985	985	Complete
6. Collaborative Programs in RD&D Consortia	1,565	1,561	1,561	Complete
7. SDG&E Program Administration	565	510	620	In Progress
Total	**$8,638**	**$8,569**	**$8,679**	

[4] As used in this Report, incurred costs mean actual booked expenditures.
[5] As used in this Report, encumbered costs are funds that are specified for contracts (D.13-11-025 at 101; Ordering Paragraph 45) or for in-house work necessary in collaboration with a contractor (D.13-11-025 at 53). They differ from commitments in that commitments are the identification of blocks of funds to be assigned to projects, whereas encumbrances specify how the commitments will be used in the projects.
[6] As used in this Report, commitment means assigned for anticipated work on a project, including anticipated contractual commitments, equipment purchases, software licenses, associated technical work by the SDG&E project team, and other expenses directly associated with the project work.

1. EPIC-1 Projects

Project 1: Smart Grid Architecture Demonstrations

All project activities were completed in 2017. IEC 61850 was identified as a principal component of the new architecture. A representative test system was constructed, and a total of eleven use cases were defined to demonstrate the use of IEC 61850 standards. The recommendation is that SDG&E plan for long-term migration to an architecture that incorporates IEC 61850 standards

Project 2: Visualization and Situational Awareness Demonstrations

The project was divided into three work modules.

Module 1: Visualization and Situational Awareness Demonstrations
Module 2: Visualization and Situational Awareness Demonstrations, Additional Use Case Work
Module 3: Visualization and Situational Awareness Demonstrations, Unmanned Aircraft Systems for Advanced Image Collection and Analytics

Module 1 was completed in 2017. Modules 2 and 3 were performed in 2018.

Comprehensive final reports for all three modules have been filed and are posted on the SDG&E EPIC public website. With the solutions demonstrated in this project, the SDG&E project team has made significant improvements over the state-of-the-art approaches at SDG&E in each of the areas addressed by the use cases.

Elements of work were presented at the following events: EPIC Symposium in February 2017 in Sacramento, Data Analytics Conference in September 2017 in San Diego, OSIsoft T&D User Group Meeting in September 2017 in New Orleans, EPIC Fall Symposium in October 2017 in San Diego.

Project 3: Distributed Control for Smart Grids

In 2017, the project final report was completed. The project concluded with the final task, which involved conducting extensive tests on the system, beginning with factory acceptance testing and culminating with system acceptance testing, and a final pre-commercial demonstration of the operation and performance of the system at SDG&E's Integrated Test Facility (ITF). The results of those tests and the comparison between the different approaches were documented and used to formulate findings and conclusions.

The project was presented at the EPIC Symposium on February 2017 in Sacramento, and at the EPIC Fall Symposium in October 2017 in San Diego.

Project 4: Demonstration of Grid Support Functions of Distributed Energy Resources

This project's primary focus was on pre-commercial demonstrations to assess the value of distributed energy resources (DER) grid support functions in various alternative application situations. This project consists of three modules: value assessment of grid support functions of DER, communication standards for grid support functions of DER, and demonstration and comparison of the EPRI and SDG&E DER hosting capacity analysis tools. All three modules were completed in 2017 and comprehensive final reports (with project approach, results, findings, recommendations, metrics, and value proposition sections) were prepared for each of the modules individually. For Module 1 (which was a substantial part of this project), a prime contractor was selected by competitive procurement. Three bidders responded to the solicitation. All bids passed the initial screening criterion of being responsive to the request for proposal, and they were all evaluated and scored in accordance with the evaluation criteria. Schweitzer Engineering Laboratories (SEL) was selected for the contract award. SEL was the highest scoring bidder. Modules 2 and 3 were smaller efforts for which the contractors were selected by sole source.

Project 5: Smart Distribution Circuit Demonstrations

The project concluded in 2017. The project was divided into 2 modules:

- Module 1: Demonstration of Advanced Circuit Concepts – SDG&E selected Schweitzer Engineering Laboratory (SEL) as the prime contractor for this module. The focus was to perform pilot demonstrations of smart distribution circuit features in a laboratory for a set of selected test circuits. Using simulations and hardware-in-the-loop (HIL) testing, the desired features and upgrades were tested in the selected circuits to assess their suitability for widespread adoption.
- Module 2: Pre-Commercial Demonstration of Methodologies and Tools for Energy Storage Integration into Smart Distribution Circuits – All project activities were completed in the year 2017. The test included identification, evaluation, selection, and demonstration of methodologies and tools for prospective use in planning future energy storage projects. Test results from the test system were documented and evaluated. Chosen tools, software programs and methodologies were recommended to stakeholders.

2. EPIC-2 Projects

Project 1: Modernization of Distribution System and Integration of Distributed Generation and Storage

The project focused on a pre-commercial demonstration of a substation communication network based on the IEC 61850 communication standards. Members of SDG&E's substations and protection sections were engaged in the project planning in both project team and project stakeholder (prospective user) roles. Intelligence was gathered on the status of the IEC standards and the vendor equipment options for the demonstration. A prime contractor was added to the project team. A test system was developed, and a pre-commercial demonstration performed for selected use cases. The demonstration showed clear advantages of IEC 61850 over legacy communication standards.

Project 2: Data Analytics in Support of Advanced Planning and System Operations
All project activities were completed in 2017. The pre-commercial demonstration included ingestion of several data sources into a data lake, test build of preliminary predictive models for major electric distribution asset management use cases, and visualization development using business intelligence tools to provide insight into the health of various assets on the utility distribution system. Based on the project findings, it is recommended that SDG&E and other utility stakeholders commercially adopt and implement advanced data analytics techniques for effective asset management.

Project 3: Monitoring, Communication, and Control Infrastructure for Power System Modernization

All project activities were completed in 2017. The project focus was on pre-commercial demonstration of an Open Field Messaging Bus (Open FMB) for interoperability, peer-to-peer communication, and multiple protocol conversion. A representative test system was constructed, and a total of thirteen use cases were defined to demonstrate the use of OpenFMB for monitoring and control. As a result of this demonstration, it is recommended that work be continued to further define the OpenFMB standard so that it can be successfully utilized in future utility distribution system projects and deployments.

Project 4: System Operations Development and Advancement

All project activities were completed in the year 2017. A PHIL (Power Hardware In the Loop) test system was developed to examine improvements of the distribution system containing modern system component by optimization, using the RAMCO (Regional Aggregation Monitoring and Circuit Optimizers) and LRAM (Local Resource Aggregation and Monitoring). Results from the test system were evaluated and concluded that, the system operated as intended and optimized the distribution system. The recommendation is that stakeholders pursue this system further and commercialize it.

Project 5: Integration of Customer Systems into Electric Utility Infrastructure

The primary objective of this project was to investigate and address the evolving gateway between customers and utilities to facilitate increase in reliable deployment of clean energy technologies to support distribution systems. All project activities were completed in 2017. The project focus was on performing pre-commercial demonstration of advanced monitoring schemes, root-cause analysis tools, and assessment methodologies for safe and reliable integration and interoperability of customer systems with the distribution system and thereby increasing ratepayer satisfaction and benefits.

Project 6: Collaborative Programs in RD&D Consortia

Project development on demonstrations through collaborative R&D consortia focused on two modules. All project activities were completed in 2017.

For the project module on forecasting customer adoption of photovoltaic (PV), the project team used machine learning to identify several important attributes driving adoption for disadvantaged communities (DAC) and other locations (non-DAC) at the zip code level. Owner occupancy emerged as a key attribute explaining the difference in PV market share. The percentage of owner occupied homes is 50% for DAC zip codes compared to 63% for non-DAC zip codes. It is recommended that SDG&E not commercially adopt these methods and tools at this juncture, without more foundational work being done first.

For the module on unmanned aerial systems (UAS) data lifecycle management and deep learning demonstration, the project demonstrated integration with existing and future SDG&E infrastructure, software applications and legacy data sets with the ability to ingest, store, analyze and report on SDG&E assets derived from Geographic Information System (GIS), Power Line Systems – Computer Aided Draft and Design (PLS-CADD), unmanned aircraft system (UAS) collected data and other various sources. Three test cases were demonstrated including equipment identification, vegetation encroachment identification, and cataloging and remote asset management. It is recommended that SDG&E pursue additional evaluation of UAS technology for stakeholder groups within the company that will benefit from the aggregation of various sources of data into a data management platform that also provides advanced analytical capabilities.

II. INTRODUCTION AND OVERVIEW

A. Background on the EPIC Program

The EPIC program was established by the Commission in D.11-12-035 to provide public interest investments in applied research and development, technology demonstration and deployment, market support, and market facilitation of clean energy technologies and approaches for the benefit of ratepayers of California investor-owned utilities (IOUs). D.12-05-037 established the purposes and governance structure for the EPIC program and D.13-11-025 clarified many of the program's regulatory requirements.

The EPIC program is designed to provide funding for electric utility research, development, and demonstration (RD&D). Specific funding allotments are made to four EPIC program administrators, including SDG&E.[7] The EPIC program is intended to run until 2020 and is comprised of three triennial program cycles (*i.e.*, EPIC-1, EPIC-2, EPIC-3).

B. EPIC Program Components

The IOUs, including SDG&E, may only administer EPIC projects in the area of pre-commercial technology demonstration and deployment (TD&D). Post-commercial

[7] The EPIC administrators are the California Energy Commission (CEC), SDG&E, Southern California Edison Company (SCE) and Pacific Gas and Electric Company (PG&E).

demonstrations and deployments are not allowed. Utility participation in the early stages of the research and development process, *i.e.*, basic research and applied research for new utility-related technology, is also not allowed.

C. EPIC Program Regulatory Process

Pursuant to D.12-05-037, SDG&E was required to submit an application seeking Commission approval of an EPIC plan every three years. SDG&E submitted its First Triennial EPIC Plan for years 2012-2014 (A.12-11-002) on November 1, 2012 (EPIC-1) and received full Commission approval of its EPIC-1 Plan in D.13-11-025. No hearings were held. SDG&E submitted its Second Triennial EPIC Plan for years 2015-2017 (A.14-05-004) on May 1, 2014 (EPIC-2) and received Commission approval of its EPIC-2 Plan in D.15-04-020. No hearings were held. SDG&E submitted its Third Triennial EPIC Plan for years 2018-2020 (A.17-05-009) on May 1, 2017 (EPIC-3). The Commission approved SDG&E's EPIC-3 application in D.18-10-052, issued on November 2, 2018, with partial release of the funds and orders regarding implementation of the work and requirements that must be met for release of the balance of the funds. SDG&E is setting up a new EPIC-3 team that will launch these projects in early 2019.

In accordance with Ordering Paragraph 16 of D.12-05-037 and consistent with the Annual Report outline provided in Attachment 5 of D.13-11-025, SDG&E and the other EPIC Administrators are required to submit an annual report annually on February 28, 2013 through February 28, 2020. This is the seventh annual report submitted by SDG&E for its EPIC program.

D. Coordination among EPIC Administrators

The four EPIC Administrators have regular teleconferences and face-to-face meetings as needed to coordinate EPIC activities.

E. Transparent and Public Process

SDG&E is committed to conducting competitive procurements for those parts of the project work that require contracted services or major purchases of equipment or software. Development and issuance of request for proposals (RFPs) for two EPIC-1 projects were initiated in late 2014 and for a third EPIC-1 project in 2015. Competitive procurements for four additional EPIC projects were initiated in 2016 (including one for an EPIC-1 project and three for EPIC-2 projects). One informal competitive procurement was performed for an EPIC-2 project in 2017. No new competitive procurements were performed in completing the remaining two modules of EPIC-1, Project 2, in 2018.

SDG&E and the other EPIC Administrators are required to host at least two stakeholder meetings annually to discuss their EPIC programs, proposals, and progress.[8] On February 7, 2018, SDG&E and the other EPIC Administrators, conducted the annual EPIC Symposium in Sacramento. SDG&E also participated with the other Administrators in the EPIC Fall Workshop (November 9, 2018) in Fresno.

SDG&E established and maintains an EPIC website accessible to the public: https://www.sdge.com/epic. This website provides EPIC program information and updates, as well as SDG&E's EPIC annual reports and EPIC projects' final reports.

III. SDG&E'S EPIC BUDGET AND RELATED COSTS

A. SDG&E Authorized Budget and Incurred Costs for EPIC-1 (2012 – 2014) and EPIC-2 (2015 -2017)

Table 2 below, sets forth SDG&E's Commission-authorized EPIC budget incurred costs for EPIC-1 and EPIC-2 as of December 31, 2018.

Table 2. SDG&E Budget and Incurred Costs for EPIC-1 and EPIC-2 as of December 31, 2018 (in $ thousands)

	EPIC Triennial 1 (2012 – 2014)		EPIC Triennial 2 (2015 – 2017)	
	Technology Demonstration & Deployment	Program Administrative	Technology Demonstration & Deployment	Program Administrative
SDG&E Commission-Authorized Budget[9]	7,740	860	8,059	620
SDG&E Incurred Costs[10]	7651	826	8,073	565

[8] D.12-05-037 at 74.
[9] D.13-11-025 for EPIC-1 and D.15-04-020 for EPIC-2.
[10] Incurred costs mean actual booked expenditures.

as of December 31, 2018				

Table 3 below, sets forth SDG&E's disbursements to the CEC and Commission for EPIC-1 and EPIC-2 as of December 31, 2018.

Table 3. SDG&E's Disbursements to the CEC and Commission for EPIC-1 and EPIC-2 as of December 31, 2018 (in $ thousands)

	EPIC Triennial 1 (2012 – 2014)		EPIC Triennial 2 (2015 – 2017)	
	Technology Demonstration & Deployment	**Program Administrative**	**Technology Demonstration & Deployment**	**Program Administrative**
SDG&E Disbursements to CEC	16,127	3,024	40,624	2,991
SDG&E Disbursements to Commission for Regulatory Oversight	N/A	273	N/A	224

B. Commitments/Encumbrances[11,12] for TD&D Projects

SDG&E has committed $7,740k of its TD&D budget for the EPIC-1 cycle to the five projects in its approved First Triennial Plan. As of December 31, 2018, SDG&E has encumbered $7,514k of EPIC-1 funds for contracted activities and in-house work in collaboration with a contractor. As of December 31, 2018, SDG&E has expended $6,768k on contracted work. SDG&E has spent $883k on internal project work. The total expenditures

[11] Commitment means assigned for anticipated work on a project, including anticipated contractual commitments, equipment purchases, software licenses, associated technical work by the SDG&E project team, and other expenses directly associated with the project work.

[12] Encumbrances are funds that are specified for contracts (D.13-11-025 at 101; Ordering Paragraph 45) or for in-house work necessary in collaboration with a contractor (D.13-11-025 at 53). They differ from commitments in that commitments are the identification of blocks of funds to be assigned to projects, whereas encumbrances specify how the commitments will be used in the projects.

through December 31, 2018 on EPIC-1 TD&D project work is therefore $7,651k. Further detail is provided in Attachment B.

SDG&E has committed $8,059k of its EPIC-2 TD&D budget to the six projects in its approved EPIC-2 plan. This constitutes full commitment of the ***approved*** EPIC-2 TD&D funds. As of December 31, 2018, SDG&E has encumbered $8,059k of EPIC-2 funds for contracted activities and in-house work in collaboration with a contractor. As of December 31, 2018, SDG&E has expended $7,635k on contracted work. SDG&E has spent $438k on internal project work. The total expenditures through December 31, 2018 on EPIC-2 TD&D project work is therefore $8,073k. Further detail is provided in Appendix A.

C. Commitments/Encumbrances for Program Administration

As of December 31, 2018, SDG&E has made the following commitments for its program administration budgets: $860k for EPIC-1 and $620k for EPIC-2. SDG&E has spent a cumulative $1,391M for overall program administration expenses through 2018, which includes both EPIC-1 and EPIC-2 costs. Of this amount, $826k is attributed to EPIC-1 and $565k is attributed to EPIC-2.

D. Fund Shifting Above 5% between Program Areas

SDG&E has done no fund shifting to date.

E. Uncommitted/Unencumbered Program Funds

SDG&E does not have any ***approved*** program TD&D funds that are uncommitted as of December 31, 2018. However, there is a small difference ($68.6k) between the $7,868.6k that was authorized for EPIC-2 and the $7,800k that is committed for TD&D. The difference exists because SDG&E did not propose to invest this amount in SDG&E's Application for EPIC-2. Therefore, SDG&E's approved budget in D.15-04-020 reflects the amount proposed in its EPIC-2 Application. Should SDG&E decide to commit the $68.6k (which is currently uncommitted/unencumbered), the Commission in D.15-04-020 advised SDG&E that they would be required to submit a subsequent regulatory filing seeking approval to invest these funds.[13]

IV. SDG&E EPIC-1 PROJECTS

[13] D.15-04-020 at 34-35.

The following is a high-level summary and status report of EPIC-1 projects.

Project 1: Smart Grid Architecture Demonstrations

i. Investment Plan Period
2012-2014 (EPIC-1)

ii. Assignment to Value Chain
Distribution

iii. Objective
The specific objectives of the project were to: perform pilot demonstration of key candidate prototype building blocks of the SDG&E smart grid architecture to determine their suitability for adoption in the architecture; document the results and make recommendations of whether specific building blocks should be adopted; and, provide demonstration results to the SDG&E interdepartmental smart grid architecture team to support the implementation phase for any building blocks adopted.

iv. Scope
The distribution system architecture building blocks were created after reviewing the existing architecture, identifying next generation architecture principles, and evaluating standards and protocols for the various architectural constructs. IEC 61850 was identified as the priority building block for demonstration. A test plan was written, and testing undertaken at SDG&E's ITF. The pre-commercial demonstration for IEC 61850 included modeling and simulation of a distribution substation and two feeders that included multiple Intelligent Electronic Devices (IED) and distributed energy resources (DERs) on the circuits. Additional demonstrations also included the comparison using IEC 61850 as a communication path and Open Field Message Bus (OpenFMB) as an alternative communication path to communicate between a simulated control center and devices in the modeled substation and distribution feeders. An analysis was performed, and recommendations were made relative to adoption of IEC 61850.

v. Deliverables
A comprehensive final report was developed describing the work and results of the project.

vi. Metrics
The following metrics were identified for this project and evaluated during the pre-commercial demonstration. These metrics are not exhaustive given the pre-commercial demonstration approach for this project.

- Identification of barriers or issues resolved that prevented widespread deployment of technology or strategy
  - Identification and lowering of unreasonable or unnecessary barriers to adoption of smart grid technologies, practices, and services (P.U. Code § 8360) – Use of configuration inheritance and descriptive data point

naming supported by IEC 61850 makes the task of configuring devices in substation and feeders considerably easier when contrasted to the conventional approach. Digitization of devices using IEC 61850 can potentially lower the barriers of adoption of newer technologies within the electric infrastructure.

    - Develop standards for communication and interoperability of appliances and equipment connected to the electric grid, including the infrastructure serving the grid (P.U. Code § 8360) – The industry has many standards that exist among several standards development organizations that may be applicable to multiple layers of the power systems architecture. A key standard is the IEC 61850 protocol suite. The extent of harmonization efforts that have included IEC 61850 show that the suite has the potential of becoming a key building block in the future smart grid architecture that enable effective communication and interoperability of equipment connected to the electric grid.
- Safety, Power Quality, and Reliability (Equipment, Electricity System) – The use of IEC 61850 in the field could enable interoperability, improve protection coordination and provide effective information sharing between field devices and backend systems. The following sub-factors could be enhanced with the use of IEC 61850:
    - Increase in the number if nodes in the power system at monitoring points
    - Reduction in outage numbers, frequency, and duration.
    - Reduction in system harmonics

vii. Schedule
February 10, 2016 to December 31, 2017

viii. EPIC Funds Encumbered as of December 31, 2017
$1,406k

ix. EPIC Funds Spent as of December 31, 2017
$1,406k

x. Partners (if applicable)
n/a

xi. Match Funding (if applicable)
n/a

xii. Match Funding Split (if applicable)
n/a

xiii. Funding Mechanism (if applicable)

A combination of in-house work and pay-for-performance contracts was used. A Request for Proposal (RFP) was released in third quarter of 2016, with contractor selection completed in 2017.

xiv. Treatment of Intellectual Property (if applicable)
No IP developed.

xv. Status Update
This project was completed in 2017, and the results were summarized in the 2017 annual report. A comprehensive final report on this project was filed with that annual report and is posted on the SDG&E EPIC public web site. The project was closed out.

Project 2: Visualization and Situational Awareness Demonstrations

i. Investment Plan Period
2012-2014 (EPIC-1)

ii. Assignment to Value Chain
Distribution

iii. Objective
The objective of this demonstration project was to explore how data collected from sensors and devices can be processed, combined, and presented to system operators in a way that enhances grid monitoring and situational awareness. This project examined how data currently unexploited and separately processed can be integrated and visually presented for strategic use by system operators. When transformed and presented in a visually integrated manner, this data can be invaluable for utilities to optimize grid operations as well as provide insights in the performance of the overall utility system. This visual framework also provides insights into customers' energy consumption behavior to serve them more effectively, foster energy conservation, and reduce peak demand. The demonstration of specific visualization and situational awareness concepts will be used to help SDG&E make choices on which options should be adopted into a future visualization and situational awareness system.

iv. Scope
The work included requirements definition for the visualization and situational awareness based on where data could yield significant value, prototyping the data integration schemes, displays and algorithms, and implementing a testing plan. Project results deemed suitable for commercial adoption into SDG&E's power system were assimilated by the stakeholder operating groups at SDG&E.

The project was divided into three work modules.

Module 1: Visualization and Situational Awareness Demonstrations

Module 2: Visualization and Situational Awareness Demonstrations, Additional Use Case Work
Module 3: Visualization and Situational Awareness Demonstrations, Unmanned Aircraft Systems for Advanced Image Collection and Analytics

Module 1 was completed in 2017. Modules 2 and 3 were completed in 2018.

The focus of each module was as follows.

- Module 1 - Core visualization module:

  The work for this module included requirements definition for visualization and situational awareness based on where data could yield significant value; prototyping the data integration schemes, displays and algorithms; and implementing a test plan. The following five use cases, addressing a wide range of SDG&E business needs within the smart grid visualization area, were selected for the demonstration: Transmission Fault Location Visualization, Load Curtailment Visualization, AMI for Operations Visualization, Imagery Management, and GIS Visualization Infrastructure Modernization.

- Module 2 – Continuation of core visualization module with extended use cases on the following topics:

  - Use case 1: Visualization of electric transmission outages (Transmission Fault Location Production implementation).
  - Use case 2: Visualization of electric load curtailment.
  - Use case 3: Volt-Var Optimization application (Real time system visualization dashboards based on Distribution SCADA and AMI data for operation).
  - Use case 7: Imagery Management
  - Use case 8: Network Visualization Capability Improvement

- Module 3 - UAS data visualization module:

  Module 3 explored how UAS can be used for advanced image collection, ingestion and storage of UAS data, and how advanced data analytics could be conducted through means of a platform especially adapted to meet SDG&E's operational requirements. A common theme identified by SDG&E stakeholders was the lack of a single, centralized data repository to store, visualize and analyze the large quantities of data collected by SDG&E. The stakeholder requirements were split into the following groups: Infrastructure, Vegetation Management and Environmental Services. The pre-commercial demonstration work was focused on relevant use cases.

v. Deliverables
Three comprehensive final reports have been prepared. The report for Module 1 was filed with the 2017 annual report. The report for Modules 2 and 3 are filed with this annual report. All three reports are posted on the SDG&E's EPIC public website.

vi. Metrics
The project tracking metrics were done using milestones in the project plan. Technical project metrics included the completion of the initial specification for a visualization and situational awareness system for each module, the demonstration of a system display mock-up for each module, and the specifications and recommendations regarding adoption by SDG&E.

Also, major project results were submitted in technical papers and presentations for consideration by major technical conferences and publications.

The following value metrics were identified for this project and are further explained in the final reports for the modules:

- Safety, Power Quality, and Reliability (Equipment, Electricity System).
- Identification of barriers or issues resolved that prevented widespread deployment of technology or strategy.
- Adoption of EPIC technology, strategy, and research data/results by others.

vii. Schedule
February 10, 2016 to Dec 31, 2018

viii. EPIC Funds Encumbered as of December 31, 2017
$2,075k

ix. EPIC Funds Spent as of December 31, 2018
$2,211k

x. Partners (if applicable)
n/a

xi. Match Funding (if applicable)
n/a

xii. Match Funding Split (if applicable)
n/a

xiii. Funding Mechanism (if applicable)
xiv. A combination of in-house work and pay-for-performance contracts was used.

xv. Treatment of Intellectual Property (if applicable)
No IP developed.

xvi. Status Update
Module 1 was completed in 2017 and its comprehensive final report was filed with the 2017 annual report. Modules 2 and 3 were completed in 2018, and their comprehensive final reports are submitted with this annual report. Through the performed work, SDG&E has demonstrated novel solutions to the selected use cases, and in the process, has gained substantial experience in integrating GIS, historical, asset management, and other major SDG&E computer systems. Project results have been assimilated into use by SDG&E stakeholder business units.

Project 3: Distributed Control for Smart Grids

i. Investment Plan Period
2012-2014 (EPIC-1)

ii. Assignment to Value Chain
Distribution

iii. Objective
The objective of this project was to test alternatives for communication and control across distribution system resources to ensure that devices operate in a complementary manner and ensure optimum distribution system performance, reliability, and stability. The project tested distributed control methods and approaches to control distribution circuit resources and integrate them as part of a unified control scheme with other higher-level control systems, such as the distribution management system (DMS). The project assessed the scalability and performance of alternative control schemes.

iv. Scope

Phase 1 – Design and Development of Technical Solution: This phase will include requirements definition for the distributed control concepts to be demonstrated. The requirements definition will consider the functions, specifications, control interface, control algorithms, data models, data exchange, and security requirements for using distributed (less centralized) control in future electric utility power distribution systems. It will build on existing infrastructure in the SDG&E system.

Phase 2 – System Installation and laboratory testing at SDG&E's Integrated Test Facility (ITF): This phase will involve the installation of the test system, modeling and verification of RTDS circuit models, integration of hardware, development of control and operational schemes, development of the test plan for evaluation of the proposed distributed control concepts, and the execution of the test plan.

Phase 3 – Data Collection and Analysis for the Pre-Commercial Demonstration: This phase will include detailed analysis of the data collected, including functions of the proposed system, control methodologies of the system (including updates to existing strategies), results of testing and effect on the existing SDG&E control system, benefits, costs, challenges, and impact on the overall SDG&E distribution system and equipment, particularly with respect to operational situations.

v. Deliverables
A comprehensive final project report was developed describing the work and results of the project.

vi. Metrics
The project tracking metrics will be the milestones in the project plan. Technical metrics for this project will be based on comparing the performance of distribution system operations when various new control schemes are in place with the performance of the same operations when the control schemes are not in place. These performance metrics will include measures of power quality, electrical loss reductions, asset health maintenance, and adaptability to new device types in the distribution system.

Also, major project results will be submitted as technical papers and presentations for consideration by major technical conferences and publications.

The following metrics were identified for this project and further explained in the final report:

- Economic Benefits.
- Safety, Power Quality, and Reliability (Equipment, Electricity System).
- Identification of barriers or issues resolved that prevented widespread deployment of technology or strategy.
- Effectiveness of information dissemination.
- Adoption of EPIC technology, strategy, and research data/results by others.

vii. Schedule
January 12, 2015 to December 31, 2017

viii. EPIC Funds Encumbered as of December 31, 2017
$1,392k

ix. EPIC Funds Spent as of December 31, 2017
$1,392k

x. Partners (if applicable)
n/a

xi. Match Funding (if applicable)

n/a

xii. Match Funding Split (if applicable)
n/a

xiii. Funding Mechanism (if applicable)
SDG&E EPIC funds were applied to a combination of in-house work and a pay-for-performance contract. A prime contractor was selected by competitive procurement in the second quarter of 2016. Five bidders responded to the solicitation. All bids passed the initial screening criterion of being responsive the request for proposal, and they were all evaluated and scored in accordance with the evaluation criteria. Quanta Technology, LLC was selected for the contract award. Quanta was the highest scoring bidder.

xiv. Treatment of Intellectual Property (if applicable)
No IP developed.

xv. Status Update

This project was completed in 2017, and the results were summarized in the 2017 annual report. A comprehensive final report on this project was filed with that annual report and is posted on the SDG&E EPIC public web site. The project was closed out.

Project 4: Demonstration of Grid Support Functions of Distributed Energy Resources

i. Investment Plan Period
2012-2014 (EPIC-1)

ii. Assignment to Value Chain
Distribution

iii. Objective
The objective of EPIC-1, Project 4, Demonstration of Grid Support Functions of Distributed Energy Resources (DER) was to demonstrate grid support functions of DER, which can improve distribution system operations. In other words, the objective was to assess the viability of using DER to provide non-traditional functions, such as volt/VAr optimization, fast-response peaking or emergency power, peak shaving, and distribution system status information. The chosen sub-projects and modules quantified the value of specific grid support functions in specific application situations and provided a basis for SDG&E to determine which functions it wants to pursue commercially in the development of its smart grid. This project consisted of three modules: value assessment of grid support functions of DER, communication standards for grid support functions of DER, and demonstration and comparison of the EPRI and SDG&E DER hosting capacity analysis tools.

iv. Scope

As previously mentioned, this project was broken into three modules: value assessment of grid support functions of DER, communication standards for grid support functions of DER, and demonstration and comparison of the EPRI and SDG&E DER hosting capacity analysis tools. The scope of each module is described individually below:

Module 1: This module addresses value assessment of grid support functions of DER, to demonstrate and determine the viability of specific DER functions and to identify which, if any, grid support functions of DER and application situations (use cases) should be pursued in advanced distribution system automation.

Module 2: This module addresses pre-commercial demonstration of communication standards for grid support functions of DER. Furthermore, it investigates how the choice of communication standards may affect functionality of DER in the distribution systems.

Module 3: This module addresses pre-commercial demonstration of EPRI's Distribution Resource Integration and Value Estimation (DRIVE) tool. Moreover, it compares SDG&E's Iterative Integration Capacity Analysis (ICA) tool with DRIVE tool and defines the pros and cons of each method. A set of recommendations was made for enhancement of hosting capacity estimation techniques at SDG&E.

v. Deliverables

The key deliverable for each module of this project was a comprehensive final report on the procedure, findings, and results. A section on conclusions and recommendations, and a separate section on metrics and value proposition completed each report. Collectively, these module final reports provide:

- Descriptions of DER functions demonstrated, application situations, testing performed, and test and analysis results.
- Recommendations regarding DER functions (or communication standard or hosting capacity tool) which should be pursued commercially and adopted by SDG&E.
- Recommendations for technology transfer of knowledge gained (on function viability and interoperability system requirements to support functions) into commercial practice and/or to standards working groups, as may be appropriate.
- Recommendations for integration systems to encourage "plug and play" capabilities in the inverters (power conditioning systems) and other integration components.
- Analysis of the metrics and value proposition.

vi. Metrics

Technical metrics for the pre-commercial demonstration were determined during the demonstration planning phase.

One measure of success for Module 1 of this project was whether it provided a basis for deciding which DER functions warrant commercial pursuit in future distribution system development. Metrics for this module also included the identification of suitable interoperability requirements, interconnection systems, and communication protocols that support the functions.

In Module 2, the metrics included a determination of which communication standards are preferred to support the adoption of viable grid support functions.

In Module 3 of this project, the metrics addressed the pros and cons of the SDG&E hosting capacity tool in comparison with the EPRI DRIVE DER hosting capacity tool.

vii. Schedule
April 1, 2014 to December 31, 2017

viii. EPIC Funds Encumbered as of December 31, 2017
$1,200K

ix. EPIC Funds Spent as of December 31, 2017
$1,201K

x. Partners (if applicable)
n/a

xi. Match Funding (if applicable)
n/a

xii. Match Funding Split (if applicable)
n/a

xiii. Funding Mechanism (if applicable)
EPIC funding of an internal SDG&E project team working with a pay-for-performance prime contractor. For Module 1 (which was a substantial part of this project), a prime contractor was selected by competitive procurement. Three bidders responded to the solicitation. All bids passed the initial screening criterion of being responsive to the request for proposal, and they were all evaluated and scored in accordance with the evaluation criteria. Schweitzer Engineering Laboratories (SEL) was selected for the contract award. SEL was the highest scoring bidder. Modules 2 and 3 were smaller efforts for which the contractors were selected by sole source.

xiv. Treatment of Intellectual Property (if applicable)
No IP developed.

xv. Status Update
This project was completed in 2017, and the results were summarized in the 2017 annual report. The project was subdivided into three modules, and a comprehensive final report on each module was filed with that annual report and posted on the SDG&E EPIC public web site. The project was closed out.

Project 5: Smart Distribution Circuit Demonstrations

i. Investment Plan Period
2012-2014 (EPIC-1)

ii. Assignment to Value Chain
Distribution

iii. Objective
The objective of this project was to perform pilot demonstrations of smart distribution circuit features and associated simulation work to identify best practices for integrating new and existing distribution equipment in these circuits. Simulations took advantage of hardware-in-loop testing with a real-time digital simulator currently available at SDG&E. Using simulations to optimize one particular circuit, desired features were tested in that circuit to assess their suitability for widespread commercial adoption.

iv. Scope
The project included laboratory testing of alternative distribution circuit components and designs, and it included detailed examination of evaluation tools for integration of energy storage. Tests were staged, and data was taken. Data analysis was performed, and recommendations were made on best practices for robust distribution circuit practices in the future.

The project was broken into two modules:

- Module 1: Demonstration of Advanced Circuit Concepts: The focus of this module was to perform pilot demonstrations of smart distribution circuit features in a laboratory for a set of selected test circuits. Using simulations and hardware-in-the-loop (HIL) testing, the desired features and upgrades were tested in the selected circuits to assess their suitability for widespread adoption.
- Module 2: Pre-Commercial Demonstration of Methodologies and Tools for Energy Storage Integration into Smart Distribution Circuit: The chosen focus of this specific project module was on pre-commercial demonstration of

methodologies and tools for energy storage integration into smart distribution circuits. The work included identification, evaluation, selection and demonstration of methodologies and tools for prospective use in planning future energy storage projects.

v. Deliverables

Comprehensive final project reports were developed for both modules describing the work and results.

vi. Metrics

The project tracking metrics included the milestones in the project plan. Technical metrics were developed to guide the actual demonstration work. In general, the ultimate measure of success was having a benchmark future distribution circuit design concept that helps advance future distribution system development. The circuit design can assimilate a wide variety of existing and emerging device types and has a protection system that allows this assimilation to be done without compromising reliability or safety.

The following metrics were identified for Module 1 and further explained in the final report:

- Economic Benefits.
- Safety, Power Quality, and Reliability (Equipment, Electricity System).
- Identification of barriers or issues resolved that prevented widespread deployment of technology or strategy.
- Effectiveness of information dissemination.
- Adoption of EPIC technology, strategy, and research data/results by others.

The following metrics were identified for Module 2 and further explained in the final report.

- **Potential energy and cost savings**
  - Avoided procurement and generation costs
  - Nameplate capacity (MW) of grid-connected energy storage – use methodology and tools to target ESS size for each application
- **Economic benefits**
  - Maintain/reduce capital costs (by proper sizing and increase in utilization factor)
  - Non-energy economic benefits
- **Safety, Power Quality, and Reliability (Equipment, Electricity System)**
  - Outage number, frequency and duration reductions
  - Electric system power flow congestion reduction
  - Forecast accuracy improvement
  - Public safety improvement and hazard exposure reduction

- Reduced flicker and other power quality differences

- **Effectiveness of information dissemination**
  - A technology transfer plan was presented in the final report.

vii. Schedule
July 7, 2014 to December 31, 2017

viii. EPIC Funds Encumbered as of December 31, 2017
$1,441k

ix. EPIC Funds Spent as of December 31, 2017
$1,441k

x. Partners (if applicable)
n/a

xi. Match Funding (if applicable)
n/a

xii. Match Funding Split (if applicable)
n/a

xiii. Funding Mechanism (if applicable)
For both Module 1 and Module 2, SDG&E EPIC funds were applied to support a team of internal technical staff and pay-for-performance contractors. The contractors were selected as per SDG&E procurement policy.

xiv. Treatment of Intellectual Property (if applicable)
No IP developed.

xv. Status Update
This project was completed in 2017, and the results were summarized in the 2017 annual report. The project was subdivided into two modules, and a comprehensive final report on each module was filed with that annual report and posted on the SDG&E EPIC public web site. The project was closed out.

V. SDG&E EPIC-2 PROJECTS

The following is a high-level summary and status report of EPIC-2 projects.

Project 1: Modernization of Distribution System and Integration of Distributed Generation and Storage

i. Investment Plan Period
2015-2017 (EPIC-2)

ii. Assignment to Value Chain
Distribution

iii. Objective
The objective of this project was to demonstrate distribution system infrastructure modernization solutions, including advances in distribution system design to enable use of new technologies, such as power electronic components, new protection systems, distributed generation and alternative storage technologies. The work built on the current state of the art for these devices and any track record that was available from the industry.

iv. Scope
This project has been focused on the pre-commercial demonstration of the international standard, IEC 61850, in a substation network. Investigating the application and usefulness of IEC 61850 will help SDG&E to assess the benefits and challenges of implementing this standard in substations. This pre-commercial demonstration will also investigate the interoperability of multiple vendor products.

This project will create knowledge to help SDG&E assess whether IEC 61850 should be adopted commercially and what the adoption requirements and processes would be. The knowledge may help other utilities with similar decision processes.

v. Deliverables
A comprehensive final report on the work and results of the project.

vi. Metrics
The following metrics were identified for this project. Given the proof of concept nature of this EPIC project, these metrics are forward looking to prospective adoption of IEC 61850 standards.

The main protection concerns that were identified in this project were speed and reliability. The following metrics address these concerns.

- Potential energy and cost savings:
  Due to reduced engineering efforts in the design process using IEC 61850 equipment, cost savings flow through to ratepayers. The integrated engineering tools make it easier to design the substation and test the equipment before deployment, which is hard to achieve now and is more time consuming with current legacy systems.

- Economic benefits:

- Maintain/reduce operation and maintenance costs:
  - IEC 61850 digital equipment allows easier maintenance and debugging of the equipment using advanced embedded software tools.
  - The labor costs associated with the process bus implementation are reduced significantly. This is primarily due to the reduction in wiring.
- Improvements in system operation efficiency and adding automation features:
  - Operation efficiency can be improved using IEC 61850 equipment especially with the new peer-to-peer communication feature, which allows major improvements of operations. More equipment can be monitored and operated to reduce the causes of outages and improve the reliability. Peer-to-peer communication also allows increased functional capabilities in the protection scheme.

vii. Schedule
January 4, 2016 to December 31, 2017

viii. EPIC Funds Encumbered as of December 31, 2017
$2,009k

ix. EPIC Funds Spent as of December 31, 2017
$2,032k

x. Partners (if applicable)
n/a

xi. Match Funding (if applicable)
n/a

xii. Match Funding Split (if applicable)
n/a

xiii. Funding Mechanism (if applicable)
A combination of in-house work and a pay-per-performance contract were used.

xiv. Treatment of Intellectual Property (if applicable)
No IP developed.

xv. Status Update
This project was completed in 2017, and the results were summarized in the 2017 annual report. A comprehensive final report on this project was filed with that annual report and is posted on the SDG&E EPIC public web site. The project was closed out.

Project 2: Data Analytics in Support of Advanced Planning and System Operations

i. Investment Plan Period
2015-2017 (EPIC-2)

ii. Assignment to Value Chain
Distribution

iii. Objective
This project was designed to address the anticipated "data tsunami" associated with more widespread system monitoring and more widespread use of controllable devices in the power system. It helped to create better data management. It also demonstrated solutions for the data management issues and challenges expected to accompany the extensive amount of real-time and stored data being archived from field devices and identify the data mining procedures and the data-archiving methods, utilizing this data to improve power system operations. Solutions that are deemed to be best practices were documented for use in improving the data management systems that support power system operations. The project results are expected to benefit SDG&E and other utilities.

iv. Scope
This demonstration project determined the quantity and location of data-generating devices in the power system, the generation capabilities of these devices, and how the resulting data was being stored and archived. The project determined how the use of vast amounts of data to support the power system operations, such as pot event analysis, predictive maintenance, and asset management. The project identified and performed advanced analytics for various types of distribution system asset failures. The project demonstrated integration of multiple data sources into a data lake, creation of test models to perform predictive, and created visualizations for business user engagement. The pre-commercial demonstration system was used to demonstrate specific use cases from the roster of use cases developed by SDG&E's Electric Distribution Engineering (EDE) team.

v. Deliverables
A comprehensive final report was developed describing the work and results of the project.

vi. Metrics
The following metrics were identified for this project and evaluated during the course of the pre-commercial demonstration. These metrics are not exhaustive given the pre-commercial demonstration approach for this project.

- Safety, Power Quality, and Reliability (Equipment, Electricity System) – The use of machine learning and advanced data analytics can help stakeholders predict the failure of equipment based on current and

historical operational data and other data. The following sub-factors could be analyzed with advanced data analytics:
    - Number of outages, frequency and duration reductions
    - Forecast accuracy improvement
    - Public safety improvement
    - Utility worker safety improvement
- Economic Benefits – Advanced data analytics can provide significant economic benefits by helping the identification of failing or aging equipment, before they fail, thereby reducing operational expenditures and planning capital expenditures effectively. The following sub-factors could be affected with advanced data analytics:
    - Maintain/reduce operations and maintenance costs
    - Maintain/reduce capital costs
    - Improvement in system operation efficiencies

vii. Schedule
October 16, 2015 to December 31, 2017

viii. EPIC Funds Encumbered as of December 31, 2017
$1,111k

ix. EPIC Funds Spent as of December 31, 2017
$1,098k

x. Partners (if applicable)
n/a

xi. Match Funding (if applicable)
n/a

xii. Match Funding Split (if applicable)
n/a

xiii. Funding Mechanism (if applicable)
Combination of in-house work and pay-for-performance contracts. A Request for Proposal (RFP) was released in third quarter of 2016, with contractor selection completed in 2017.

xiv. Treatment of Intellectual Property (if applicable)
No IP developed.

xv. Status Update
This project was completed in 2017, and the results were summarized in the 2017 annual report. A comprehensive final report on this project was filed with that annual report and is posted on the SDG&E EPIC public web site. The project was closed out.

Project 3: Monitoring, Communication, and Control Infrastructure for Power System Modernization

i. Investment Plan Period
2015-2017 (EPIC-2)

ii. Assignment to Value Chain
Distribution

iii. Objective
The objective of this project was to demonstrate advanced monitoring, communication and control infrastructure needed to operate an increasingly complex power system infrastructure. In other words, to test system controls to "sort" data and use what is helpful and useful.

iv. Scope
To achieve this objective, the project undertook a demonstration to evaluate an Open Field Message Bus (OpenFMB) with respect to SDG&E's existing architecture and vision for the future. The project demonstrated interoperability through secure, peer-to-peer control and communication between multiple distribution system equipment types based on existing standards. The approach included development of a test system for use in a pre-commercial demonstration to evaluate and demonstrate OpenFMB in a controlled environment within SDG&E's laboratory. The test system consisted of several controllable utility distribution system devices networked to mimic two feeders on SDG&E's distribution network. These devices were networked using differing network technologies designed to reproduce field conditions. The project also demonstrated communications interoperability among different vendor products through the use of adapters which converted those products' legacy communications technologies to OpenFMB. The OpenFMB network used multiple communications protocols, including MQTT, DDS, and R-GOOSE, to accomplish 13 use cases developed for this project. The pre-commercial demonstration system was subjected to a number of test cases to verify its correct operation and validate the use cases.

v. Deliverables
A comprehensive final report was developed describing the work and results of the project.

vi. Metrics
The following metrics were identified for this project and evaluated during the course of the pre-commercial demonstration. These metrics are not exhaustive given the pre-commercial demonstration approach for this project.

- Identification of barriers or issues resolved that prevented widespread deployment of technology or strategy
    - Develop standards for communication and interoperability of appliances and equipment connected to the electric grid, including the infrastructure serving the grid (P.U. Code § 8360) – The EPIC project demonstrated the potential value of OpenFMB in addressing interoperability issues that exist in the electric system today, with multiple vendor technologies/systems unable to interface or interact with each other in a seamless manner. OpenFMB could provide a framework that enables the coexistence of traditional IEDs or devices that operate in a centralized manner with new IEDs or devices (especially DERs) that have the capability to operate in a decentralized manner.
    - Identification and lowering of unreasonable or unnecessary barriers to adoption of smart grid technologies, practices, and services (P.U. Code § 8360) – This EPIC project established a potential OpenFMB framework that could be implemented in the secondary layer that sits between the enterprise layer in a utility control center, and the primary layer that sits on multiple devices or equipment in the field. Next generation of IEDs or DERs may provide the necessary communication technology and application framework that enable peer to peer communication between devices and routes the information through the OpenFMB framework to disparate systems in the backend.
- Safety, Power Quality, and Reliability (Equipment, Electricity System) The use of OpenFMB framework to deploy decentralized applications could enable interoperability and improve information sharing between field devices and backend systems. The following sub-factors could be enhanced with the use of OpenFMB:
    - Reduction in outage numbers, frequency, and duration.
    - Reduction in system harmonics
    - Increase in the number if nodes in the power system at monitoring points
    - Public safety improvement and hazard exposure reduction

vii. Schedule
November 1, 2015 to December 31, 2017

viii. EPIC Funds Encumbered as of December 31, 2017
$1,305k

ix. EPIC Funds Spent as of December 31, 2017
$1,305k

x. Partners (if applicable)
n/a

xi. Match Funding (if applicable)
n/a

xii. Match Funding Split (if applicable)
n/a

xiii. Funding Mechanism (if applicable)
SDG&E EPIC funds applied to a combination of in-house work and a pay-for-performance contract. An RFP was released in third quarter of 2016, with contractor selection completed in 2017.

xiv. Treatment of Intellectual Property (if applicable)
No IP developed.

xv. Status Update
This project was completed in 2017, and the results were summarized in the 2017 annual report. A comprehensive final report on this project was filed with that annual report and is posted on the SDG&E EPIC public web site. The project was closed out.

Project 4: System Operations Development and Advancement

i. Investment Plan Period
2015-2017 (EPIC-2)

ii. Assignment to Value Chain
Distribution

iii. Objective
The objective of this project was to support continued modernization of SDG&E's power system via demonstrations of improved capabilities in system operations. The project demonstrated a systematic process for the realignment of operating practices with advances in technology, software and standards used in the power system. The realignment is broad and addresses system integration issues and technology transfer.

iv. Scope
This project was focused on a distributed, autonomous, and scalable architecture, which included robust communication architecture and a hardware and software platform for aggregating and dispatching coordinated net-load resources (the difference between the load and power from Distributed Energy Resources (DER) in localized regions of the distribution system). The architecture included a concept of Localized Residential Aggregation and Monitoring (LRAMs) and Regional Aggregation, Monitoring & Circuit Optimizer (RAMCOs) for control and aggregation of customer-owned distributed generation and controllable loads

on distribution systems. The project work was performed by a team comprised of SDG&E technical staff and the contractor.

v. Deliverables
A comprehensive final report on the project.

vi. Metrics
The following metrics were used to evaluate the project from different perspectives including Project Success Factors, Project Implementation Milestones, and Technical Achievements.

- **Potential energy and cost savings**
  - Number and total nameplate capacity of distributed generation facilities – 15 sites were included in the demonstration.
  - Peak load reduction (MW) from summer and winter programs-- One of the implemented use cases was focused on circuit level load management and emergency dispatch. Based on aggregated resources, up to 20% load reduction was achieved.
- **Economic benefits**
  - Reduction in electrical losses in the transmission and distribution system – The demonstrated method incorporated Volt/VAr management at the primary and secondary levels, to reduce kVA and losses (up to 3% in the tested case).
  - Number of operations of various existing equipment types (such as voltage regulators) before and after adoption of a new smart grid component, as an indicator of possible equipment life extensions from reduced wear and tear – The propose method utilized fast action of DERs and secondary resources to reduce voltage and load fluctuations and enhance life cycle. Unnecessary tap operations were eliminated. Capacitor switching was prevented.
- **Safety, Power Quality, and Reliability (Equipment, Electricity System**
  - Electric system power flow congestion reduction – In the emergency mode of the control platform, the circuit level power flow and demand were managed through control of aggregated resources to prevent congestion.
  - Increase in the number of nodes in the power system with monitoring capability – Real time monitoring and 5-minute or 10-minute system prediction were included as an integral part of the platform design. A phasor measurement unit system also provided high-resolution data for enhanced visualization.
- **Identification of barriers or issues resolved that prevented widespread deployment of technology or strategy**
  - Increased use of cost-effective digital information and control technology to improve reliability, security, and efficiency of the electric grid (P.U. Code § 8360) – Integration between SCADA/DMS and the DER aggregation platform was identified as a cost-effective solution to ensure integrity of the system.

- **Effectiveness of information dissemination**
  - Stakeholder participation in workshops – Project stakeholders within SDG&E were selected and invited to workshops.
  - Technology transfer – A plan was made for knowledge transfer through journals and conferences. A panel presentation was accepted for DistribuTECH 2018, in San Antonio (presented in January 2018).

vii. Schedule
November 11, 2015 to December 31, 2017

viii. EPIC Funds Encumbered as of December 31, 2017
$1,088k

ix. EPIC Funds Spent as of December 31, 2017
$1,088k

x. Partners (if applicable)
n/a

xi. Match Funding (if applicable)
n/a

xii. Match Funding Split (if applicable)
n/a

xiii. Funding Mechanism (if applicable)
A combination of in-house work and a pay-for-performance contract was used.

xiv. Treatment of Intellectual Property (if applicable)
No IP developed.

xv. Status Update
All project activities were completed in the year 2017. The project team held working sessions to define the baseline evaluation, concept of operations, use cases, other technical details, project schedule and resource management. Based on use cases, engineering and design, the test plan and test system were developed. The pre-commercial demonstration was carried out at the ITF, after successful factory acceptance and site acceptance tests. A comprehensive final report was developed, including the pre-commercial demonstration description, test result analysis, findings, recommendations, metrics, value proposition and conclusions.

Project 5: Integration of Customer Systems into Electric Utility Infrastructure

i. Investment Plan Period

2015-2017 (EPIC-2)

ii. Assignment to Value Chain
Distribution

iii. Objective
The project addressed the evolving gateway between customers and utilities. Specifically, it demonstrated the safe and reliable interoperability of customer systems with the distribution and transmission system and California Independent System Operator (CAISO) operations to improve grid operations and thereby increase ratepayer satisfaction and benefits.

iv. Scope
Alternative solutions for successful customer interoperability with utility systems were identified. Requirements for integration of these solutions with utility systems were specified. Promising interoperability systems were demonstrated to create a knowledge base to support decisions on prospective commercial deployment of the systems. The work was performed by a team comprised of SDG&E technical staff and a contractor.

v. Deliverables
A comprehensive final report on the work and the results of the project were delivered after project completion.

vi. Metrics
Project tracking metrics included whether the SDG&E/contactor project team met milestones in the project plan. Technical metrics for the demonstration work were identified during performance of the demonstration. Metrics for this project are based on comparing the performance of power system operations when various interoperability solutions are in place with the performance of operations when they are not in place. The commercial adoption of this project will be impacted by the following metrics:

- Potential energy and cost savings
  - The project demonstrated new technologies and analysis methods for monitoring, visualization, and root-cause analysis of distribution systems by using various measurement techniques and data sources and integrating them in one platform to provide a unique monitoring and visualization user experience. This will create significant cost savings through reducing the required nameplate capacity of energy storage and distribution generation facilities due to the enhancement of the operations by providing additional means of awareness about the system behavior.
  - Avoided procurement and generation costs – Accurate monitoring enables utilities to predict generation costs especially through predicting dynamic events caused by varying characteristics of DER energy productions, loading effect of electric vehicle charging stations, and

power electronic apparatus.

- Economic Benefits
  - Operation costs of the system can be significantly reduced by increased awareness and monitoring capability of the system.
- Safety, Power Quality, and Reliability
  - Electric system power flow congestion reduction – Any possible congestion might be diminished due to the improved monitoring, and visibility of the system. Any probable failure, or transient behavior can be properly predicted to avoid possible damage to the personnel, or equipment.
  - Forecast accuracy improvement – With improved visibility of the system, better forecasting capability is provided for the system, and any undesired behavior can be avoided by properly designing protection systems.
  - Utility worker safety improvement and hazard exposure reduction– Utility workers safety can be considerably improved by enhanced awareness of distribution assets in the real-time mode. Other obtained safety related improvements include facilitated root cause analysis, operator and engineers training, and assessment of operation and design procedures for new technologies and approaches.
  - Increase in the number of nodes in the power system with monitoring capability–This project provided more visibility, and situational awareness through increasing number of devices which monitor the system performance.
- Identification of barriers or issues resolved that prevented widespread deployment of technology or strategy

This project was successful in completing demonstrations of candidate interoperability solutions to create knowledge that will support SDG&E decisions regarding commercial adoption.

In addition, key results are presented in the final report are being submitted for consideration for publication or presentation in relevant technical journals and conferences.

vii. Schedule
October 16, 2015 to December 31, 2017

viii. EPIC Funds Encumbered as of December 31, 2017
$985k

ix. EPIC Funds Spent as of December 31, 2017
$985k

x. Partners (if applicable)

n/a

xi. Match Funding (if applicable)
n/a

xii. Match Funding Split (if applicable)
n/a

xiii. Funding Mechanism (if applicable)
SDG&E EPIC funding applied to internal project team work and a pay-for-performance contract.

xiv. Treatment of Intellectual Property (if applicable)
No IP developed.

xv. Status Update
This project was completed in 2017, and the results were summarized in the 2017 annual report. A comprehensive final report on this project was filed with that annual report and is posted on the SDG&E EPIC public web site. The project was closed out.

Project 6: Collaborative Programs in RD&D Consortia

i. Investment Plan Period
2015-2017 (EPIC-2)

ii. Assignment to Value Chain
Distribution

iii. Objective
The objective of this project was to accomplish highly leveraged demonstration work through collaborative projects in industry R&D consortia. This included information and intelligence leveraging by better informing the project content in EPIC activities with the knowledge of relevant activities occurring in a worldwide sense.

iv. Scope
The project team worked with R&D consortia to organize pre-commercial demonstration projects that focused on two modules:

- Demonstration of methodology and tools for estimating propensity for customer adoption of photovoltaics – The focus of this project module was to identify methodologies and tools for determining the primary drivers for residential photovoltaic (PV) adoption, predict residential PV adoption over time, and to demonstrate selected methods on a use case (*e.g.*, propensity to adopt PV on the zip code level). The effort also developed recommendations about whether to adopt all or some of the methods and tools on a commercial basis. The project team focused specifically on residential sector PV market adoption. Additionally, the project team conducted machine learning (ML) analytics on disadvantaged communities (DAC) zip codes and evaluated the difference in propensity to adopt solar PV between DAC and other zip codes.

- Unmanned aerial systems data lifecycle management and deep learning demonstration – The focus of this project module was to demonstrate tools that ingested and analyzed data collected by means of unmanned aircraft systems (UAS), existing red, green & blue (RGB) imagery, geographic information systems (GIS), power line systems – computer aided design and drafting (PLS-CADD) and other various inspection data types. The project module demonstrated the tools' ability to automatically identify and tag assets shown in RGB imagery, specifically avian covers, in real-world locations through machine learning. Additional identification of vegetation modeled using light imaging detection and ranging (LiDAR) data that encroached into pre-determined zone(s) around electrical wires provided a road map for future proactive vegetation maintenance efforts.

v. Deliverables

Two comprehensive final reports for the two project modules were developed describing the work and results of the project modules.

vi. Metrics

The commercial adoption methodologies and tools for estimating propensity for customer adoption of photovoltaics will be impacted by the following metrics.

- Potential energy and cost savings
    - Avoided customer energy use (kWh saved) – The use of tools to estimate customer adoption of PV would lead to understanding the contribution of electric load from PV systems, which in turn will provide the customers with reduced energy usage and economic savings.
    - Avoided procurement and generation costs – Accurate estimation of customer PV adoption rates would enable utilities to estimate the avoided cost to procure energy from sources that might be inefficient or contribute to environmental pollution.

- Environmental benefits
    - Greenhouse Gas (GHG) emissions reductions – Adoption of PV would lead to reduced emissions from fossil fuel-based sources which would have to be used in absence of renewable resources like PV.

The project metrics used to evaluate and test UAS technology and machine learning tools include:

- Habitat area disturbance reductions – UAS technologies allow for a remotely operate vehicle to access sensitive habits without impacting the land through vehicular are personnel incursions. The use cases demonstrated a process to capture and analyze electrical facilities, surrounding vegetation and terrain features from an aerial drone. The UAS technology can reduce habitat area disturbance by replacing some required physical inspections with UAS derived inspections.
- Wildlife fatality reductions (electrocutions, collisions) – This project module studied the feasibility of combining UAS derived imagery with deep learning analytics to determine the location and condition of avian covers on electrical facilities. The avian covers provide a level of protection against electrocution for birds with large wing spans resting on electrical distribution and transmission poles. Currently the avian covers are assessed by physical inspection taken from ground observation on scheduled maintenance intervals. UAS data capture and associated deep learning analytics could provide increase inspections, improved evaluation of the presence and condition of avian covers resulting in reducing the risk to wildlife.
- Utility work safety improvement and hazardous exposure reduction – This project module studied several uses case for utilizing UAS technology and machine learning analytics to remotely observe, measure and catalog electrical facilities and surrounding terrain. The technology and process remove utility workers from making physical inspection where in many cases required access through hazardous terrain and complete inspections in close proximity to energized facilities and equipment.

vii. Schedule
March 1, 2016 to December 31, 2017

viii. EPIC Funds Encumbered as of December 31, 2017
$1,561k

ix. EPIC Funds Spent as of December 31, 2017
$1,565k

x. Partners (if applicable)
n/a

xi. Match Funding (if applicable)
n/a

xii. Match Funding Split (if applicable)
n/a

xiii. Funding Mechanism (if applicable)
SDG&E EPIC funds applied to an internal team and collaborative consortium to define, set up, and execute two collaborative pre-commercial demonstration project modules.

xiv. Treatment of Intellectual Property (if applicable)
No IP developed.

xv. Status Update
This project was completed in 2017, and the results were summarized in the 2017 annual report. The project was subdivided into two modules, and a comprehensive final report on each module was filed with that annual report and posted on the SDG&E EPIC public web site. The project was closed out.

VI. CONCLUSION

A. Key Results for 2018 for SDG&E EPIC Projects

As of December 31, 2018, SDG&E has completed all technical project work for its 11 Commission-approved EPIC-1 and EPIC-2 projects. Ten of these projects were completed in 2017, and one module of the 11^{th} project was completed in 2017. The remaining two project modules of the 11^{th} project were completed in 2018. Additionally, tech transfer activities for all the projects were continued in 2018. This activity included:

- Completing the annual report for 2017 and filing it by February 28, 2018.
- 12 presentations given on EPIC-1 and EPIC-2 project results in 2018 at major industry technical conferences, the EPIC Symposium, and the Fall EPIC Workshop. A complete listing of SDG&E's external EPIC papers and presentations is provided on the SDG&E public web site. The documentation for the external presentations at major industry technical conferences is available from the conference organizers, not from SDG&E. The comprehensive final reports for the projects on the SDG&E public website contain the complete documentation of the project work.
- Advice given, as needed, to the internal stakeholders who are using the project results.
- Lunch and learn sessions for internal staff for all modules of all EPIC-1 and EPIC-2 projects.
- Making EPIC information available at Earth Day Fair booth.

Attached to this Report as Appendices 1 and 2, are the final reports for the two EPIC project modules that were completed in 2018. These EPIC final reports are also available on the SDG&E EPIC website at www.SDGE.com/EPIC.

B. Next Steps for SDG&E's EPIC Program

The annual report for 2019 will be completed and filed by the deadline of February 28, 2020.

For the EPIC-1 and EPIC-2 projects, $14,457k was awarded to contractors through December 31, 2018.

SDG&E's EPIC-3 application was approved by the Commission in November 2018, with release of 2/3 of the funds requested in the application. The remaining funds are being held, pending approval of a Research Administration Plan (RAP) to be jointly prepared by the IOU EPIC Administrators. SDG&E has collaborated with the internal stakeholders for the projects in its application and selected the first four of its EPIC-3 project to be launched first. The internal budget requisitions have been approved to begin work on these four projects in January 2019. They will be covered in the next annual report.

ATTACHMENT B

SDG&E 2018 EPIC PROJECT STATUS
(EXCEL FILE)

Investment Program Period	Program Administrator	Project Name	Project Type	Brief Description of the Project (objective; scope; deliverables; schedule)	Date of the Award	Was this project awarded in the immediately prior calendar year?	Assignment to Value Chain	Encumbered Funding Amount ($000)	Committed Funding Amount ($000)	Funds Expended to date: Contract/Grant Amount ($000)	Funds Expended to date: In house expenditures ($000)	Funds Expended to date: Total Spent to date ($000)	Administrative and overhead costs to be incurred for each project	Leveraged Funds	Partners	Match Funding	Match Funding Split	Funding Mechanism	Intellectual Property	Identification of the method used to grant awards	If competitively selected, provide the number of bidders passing the initial pass/fail screening for project	If competitively selected, provide the name of selected bidder.	If competitively selected, provide the rank of the selected bidder in the selection process.	If competitively selected, explain why the bidder was not the highest scoring bidder, explain why a lower scoring bidder was selected.	If interagency or sole source agreement, specify date of notification to the Joint Legislative Budget Committee (JLBC) was notified and date of JLBC authorization. (This column is applicable to the CEC only.)	Does the recipient for this award identify as a California-based entity, small business, or businesses owned by women, minorities, or disabled veterans?	How the project leads to technological advancement or breakthroughs to overcome barriers to achieving the state's statutory energy goals (This column is applicable to the CEC only.)	Applicable metrics	Update
1st triennial (2012-2014)	SDG&E	Smart Grid Architecture Demonstrations	Pre-commercial Demonstration	The specific objectives of the project were to: perform pilot demonstration of key candidate prototype building blocks of the SDG&E smart grid architecture to determine their suitability for adoption in the architecture; document the results and make recommendations of whether specific building blocks should be adopted; and, provide demonstration results to support the implementation phase for any building blocks adopted.	03/15/2017	Yes	Distribution	1,406	1,406	1,349	57	1,406	N/A	0	None	0	N/A	A combination of in-house work and pay-for-performance contracts was used. A Request for Proposal (RFP) was released in third quarter of 2016, with contractor selection completed in 2017.	None to date	RFP	2	Quanta Technology, LLC	1st	N/A	N/A	Yes - (Team member AVECS)	N/A	The following metrics were identified for this project and evaluated during the course of the pre-commercial demonstration. These metrics are not exhaustive given the pre-commercial demonstration approach for this project. • Identification of barriers or issues resolved that prevented widespread deployment of technology or strategy o Identification and lowering of unreasonable or unnecessary barriers to adoption of smart grid technologies, practices, and services (PU Code § 8360) - Use of configuration inheritance and descriptive data point naming supported by IEC 61850 makes the task of configuring devices in substation and feeders considerably easier when contrasted to the conventional approach. Digitization of devices using IEC 61850 can potentially lower the barriers of adoption of newer technologies within the electric infrastructure. o Develop standards for communication and interoperability of appliances and equipment connected to the electric grid, including the infrastructure serving the grid (PU Code § 8360) - The industry has many standards that exist among several standards development organizations that may be applicable to multiple layers of the power systems architecture. A key standard is the IEC 61850 protocol suite. The extent of harmonization efforts that have included IEC 61850 show that the suite has the potential of becoming a key building block in the future smart grid architecture that enable effective communication and interoperability of equipment connected to the electric grid. • Safety, Power Quality, and Reliability (Equipment, Electricity System) - The use of IEC 61850 in the field could enable interoperability, improve protection coordination and provide effective information sharing between field devices and backend systems. The following sub-factors could be enhanced with the use of IEC 61850: o Increase in the number if nodes in the power system at monitoring points o Reduction in outage numbers, frequency, and duration.	All project activities were completed in 2017. IEC 61850 was identified as a principal component of the new architecture. A representative test system was constructed, and a total of eleven use cases were defined to demonstrate the use of IEC 61850 standards. The recommendation is that SDG&E plan for long-term migration to an architecture that incorporates IEC 61850 standards.
1st triennial (2012-2014)	SDG&E	Visualization and Situational Awareness Demonstrations	Pre-commercial Demonstration	The objective of this demonstration project was to explore how data collected from sensors and devices can be processed, combined, and presented to system operators in a way that enhances grid monitoring and situational awareness. This project looked at how data currently unexploited and separately processed can be integrated and visually presented for strategic use by system operators. When transformed and presented in a visually integrated manner, this data can be invaluable for utilities to optimize grid operations as well as provide insights	Calendar Year 2017	No	Distribution	2,075	2,301	1,598	614	2,211	N/A	0	None	0	N/A	A combination of in-house work and pay-for-performance contracts was used.	None to date	Sole Source	N/A	N/A	N/A	N/A	N/A	N/A	N/A	The project tracking metrics will be the milestones in the project plan. Technical project metrics will include the completion of the initial specification for a visualization and situational awareness system, the demonstration of a system display mock-up, and the specifications and recommendations regarding adoption by SDG&E. Also, major project results will be submitted in technical papers and presentations for consideration by major technical conferences and publications. The following metrics were identified for this project and further explained in the final report: • Safety, Power Quality, and Reliability (Equipment, Electricity System).	The project was divided into three work modules: 1. Module 1: Visualization and Situational Awareness Demonstrations 2. Module 2: Visualization and Situational Awareness Demonstrations, Additional Use Case Work 3. Module 3: Visualization and Situational Awareness Demonstrations, Unmanned Aircraft Systems for Advanced Image Collection and Analytics Module 1 was completed in 2017 and its comprehensive final report was filed with the 2017 annual report. Modules 2 and 3 were completed in 2018, and their comprehensive final reports are submitted with this annual report. Through the performed work, SDG&E has demonstrated novel solutions to the selected use cases, and in the process, has gained substantial experience in integrating GIS, historical, asset management, and other major SDG&E computer systems. Project results have been assimilated into use by SDG&E stakeholder business units.
1st triennial (2012-2014)	SDG&E	Distributed Control for Smart Grids	Pre-commercial Demonstration	The objective of this project was to test alternatives for communication and control across distribution system resources to ensure that devices operate in a complementary manner and ensure optimum distribution system performance, reliability, and stability. The project tested distributed control methods and approaches to control distribution circuit resources and integrate them as part of a unified control scheme with other higher-level control systems, such as the distribution management system (DMS). The project assessed the scalability and performance of alternative control schemes.	06/01/2016	No	Distribution	1,392	1,392	1,339	53	1,392	N/A	0	None	0	N/A	SDG&E EPIC funds were applied to a combination of in-house work and a pay-for-performance contract. A prime contractor was selected by competitive procurement in the second quarter of 2016.	None to date	RFP for prime contractor and sole source for consultant to help prepare the RFP.	5	Quanta Technology, LLC	1st	N/A	N/A	No	N/A	The project tracking metrics will be the milestones in the project plan. Technical metrics for this project will be based on comparing the performance of distribution system operations when various new control schemes are in place with the performance of the same operations when the control schemes are not in place. These performance metrics will include measures of power quality, electrical loss reductions, asset health maintenance, and adaptability to new device types in the distribution system. Also, major project results will be submitted as technical papers and presentations for consideration by major technical conferences and publications. The following metrics were identified for this project and further explained in the final report: • Economic Benefits. • Safety, Power Quality, and Reliability (Equipment, Electricity System). • Identification of barriers or issues resolved that prevented widespread deployment of technology or strategy. • Effectiveness of information dissemination.	2017 saw the completion of the project. The results provided quantifiable evidence that the distributed control of system resources could achieve benefits when compared to a conventional approach. Major benefits identified included: • Increase the utilization and contribution of DERs • Reduce and even prevent unintentional reverse power flow • Produce a flatter voltage profile over the length of a circuit • Bring voltage profiles back inside the permissible range after a system event • Reduce system electrical losses • Improve the power factor of a circuit • Reduce the number of operations of controllable assets like capacitor banks, voltage regulators and load tap changers • Dynamically adjust protection settings to increase system reliability The tests demonstrated that the greatest benefits were obtained when the control system was able to coordinate the control of two adjacent substations and when the regionally-based master controller was controlling the system, because it provided more possibilities for system optimization.
1st triennial (2012-2014)	SDG&E	Demonstration of Grid Support Functions of Distributed Energy Resources	Pre-commercial Demonstration	The objective of EPIC-1, Project 4, Demonstration of Grid Support Functions of Distributed Energy Resources (DER) was to demonstrate grid support functions of DER, which can improve distribution system operations. In other words, the objective was to assess the viability of using DER to provide non-traditional functions, such as volt/VAr optimization, fast-response peaking or emergency power, peak shaving, and distribution system status information. This project consisted of three modules: value assessment of grid support functions of DER, communication standards for grid support functions of DER, and demonstration and comparison of the EPRI and SDG&E DER hosting capacity analysis tools.	Calendar Year 2015 and Calendar Year 2017	No for first contract and Yes for second and third contracts	Distribution	1,200	1,200	1,118	83	1,201	N/A	0	None	0	N/A	EPIC funding of an internal SDG&E project team working with a pay-for-performance prime contractor. For Module 1 (which was a substantial part of this project), a prime contractor was selected by competitive procurement. Modules 2 and 3 were smaller efforts for which the contractors were selected by sole	None to date	RFP for prime contractor for first project module. Sole source for prime contractors for second and third modules.	3	Schweitzer Engineering Laboratories for first module. Kitu and EPRI for second and third modules respectively.	1st	N/A	N/A	No	N/A	Technical metrics for the pre-commercial demonstration were determined during the demonstration planning phase. One measure of success for Module 1 of this project was whether it provided a basis for deciding which DER functions warrant commercial pursuit in future distribution system development. Metrics for this module also included the identification of suitable interoperability requirements, interconnection systems, and communication protocols that support the functions. In Module 2, the metrics included a determination of which communication standards are preferred to support the adoption of viable grid support functions. In Module 3 of this project, the metrics addressed the pros and cons of the SDG&E hosting capacity tool in comparison with the EPRI DRIVE DER hosting capacity tool.	The three modules of this project were successfully accomplished with collaboration of the SDG&E internal team and the contractors' team. Final reports were completed individually for each module. They were carefully reviewed by the internal stakeholders, the SDG&E internal team, and the contractors' team and then revised into final form for public release.
1st triennial (2012-2014)	SDG&E	Smart Distribution Circuit Demonstrations	Pre-commercial Demonstration	The objective of this project was to perform pilot demonstrations of smart distribution circuit features and associated simulation work to identify best practices for integrating new and existing distribution equipment in these circuits. Simulations took advantage of hardware-in-loop testing with a real-time digital simulator currently available at SDG&E. Using simulations to optimize one particular circuit, desired features were tested in that circuit to assess their suitability for widespread commercial adoption.	12/04/2015	No for first contract and Yes for second contract	Distribution	1,441	1,441	1,364	77	1,441	N/A	0	None	0	N/A	For both Module 1 and Module 2, SDG&E EPIC funds were applied to support a team of internal technical staff and pay-for-performance contractors. The contractors were selected as per SDG&E procurement policy.	None to date	RFP for prime contractor and sole source for consultant to help prepare the RFP.	4	Schweitzer Engineering Laboratories for first module. Quanta Technology, LLC for second module.	1st for Schweitzer Engineering Laboratories for first module.	N/A	N/A	No	N/A	The project tracking metrics included the milestones in the project plan. Technical metrics were developed to guide the actual demonstration work. In general, the ultimate measure of success was having a benchmark future distribution circuit design concept that helps advance future distribution system development. The circuit design can assimilate a wide variety of existing and emerging device types and has a protection system that allows this assimilation to be done without compromising reliability or safety. The following metrics were identified for Module 1 and further explained in the final report: • Economic Benefits. • Safety, Power Quality, and Reliability (Equipment, Electricity System). • Identification of barriers or issues resolved that prevented widespread deployment of technology or strategy. • Effectiveness of information dissemination. • Adoption of EPIC technology, strategy, and research data/results by others. The following metrics were identified for Module 2 and further explained in the final report. • Potential energy and cost savings • Economic benefits • Safety, Power Quality, and Reliability (Equipment, Electricity System) • Effectiveness of information dissemination	The project was concluded in 2017. As mentioned, the project was broken into two modules: Module 1: Demonstration of Advanced Circuit Concepts: Developed with the assistance of Schweitzer Engineering Laboratories, Inc. This module was developed in 3 phases: o Phase 1 of the project covered the evaluation and documentation of products and technologies currently available for improved distribution circuit design, system operation, and protection. o Phase 2 of the project included selection and modeling of three diverse SDG&E distribution circuits viz., coastal-residential, urban, and desert-rural in a modeled environment for demonstration of advanced circuit concepts. The observations and results captured were analyzed and the findings from stand-alone device testing provided inputs on how to modify the existing circuits for improved reliability and performance. o Phase 3 of the project included findings and recommendations from the demonstration in Phase 2. The recommended system architecture for commercial implementation of voltage support coordination scheme is provided. Module 2: Pre-Commercial Demonstration of Methodologies and Tools for Energy Storage Integration into Smart Distribution Circuits – All project activities were completed in the year 2017. The test included identification, evaluation, selection and demonstration of methodologies and tools for prospective use in planning future energy storage projects. Test result from the test system were documented and evaluated. Chosen tools, software programs and methodologies were recommended to stakeholders.
								7,514	7,740	6,768	884	7,651																	
2nd triennial (2015 - 2017)	SDG&E	Modernization of Distribution System & Integration of Distributed Generation and Storage	Pre-commercial Demonstration	The objective of this project was to demonstrate distribution system infrastructure modernization solutions, including advances in distribution system design to enable use of new technologies, such as power electronic components, new protection systems, distributed generation and alternative storage technologies. The work was focused on pre-commercial demonstration of emerging substation communication standards.	Calendar Year 2017	Yes	Distribution	2,009	2,009	1,987	45	2,032	N/A	0	None	0	N/A	A combination of in-house work and pay-per-performance were used.	None to date	Sole Source for prime contractor and competitive bid for equipment vendors.	N/A	N/A	N/A	N/A	N/A	N/A	N/A	The following metrics were identified for this project. Given the proof of concept nature of this EPIC project, these metrics are forward looking to prospective adoption of IEC 61850 standards. The main protection concerns that were identified in this project were speed and reliability. The following metrics address these concerns. i. Potential energy and cost savings: Due to reduced engineering efforts in the design process using IEC 61850 equipment, cost savings flow through to ratepayers. The integrated engineering tools make it easier to design the substation and test the equipment before deployment, which is hard to achieve now and is more time consuming with current legacy systems.	The project was completed in 2017. Stakeholders from SDG&E's substations and protection sections worked with the internal project team and contractor to plan and review the task work in this project. Options for performing the demonstration were explored, including at an actual substation or in a laboratory. Due to cost and risk considerations, it was decided to perform the demonstration in a laboratory using a substation mock-up. Intelligence was gathered on the status of the IEC standards and the vendor equipment options for the demonstration. The project team finished a successful laboratory demonstration for several substation-protection use cases. A key recommendation coming from the project was for SDG&E to further explore commercial adoption of IEC 61850. Internal stakeholders are doing so. Other technology transfer activities have included presentations at various conferences. Included were a presentation at the IEC 61850 Europe 2017 Conference in September 2017 and acceptance for presentation at DistribuTECH 2018 (presented in January 2018). The project was also presented at EPIC Symposiums on December 1, 2016 in Sacramento and on October 18, 2017 in San Diego.
2nd triennial (2015 - 2017)	SDG&E	Data Analytics in Support of Advanced Planning and System Operations	Pre-commercial Demonstration	This project was designed to address the anticipated "data tsunami" associated with more widespread system monitoring and more widespread use of controllable devices in the power system. It helped to create better data management. It also demonstrated solutions for the data management issues and challenges expected to accompany the extensive amount of real-time and stored data being archived from field devices and identify the data mining procedures and the data-archiving methods, utilizing this data to improve power system operations. Solutions that are deemed to be best practices were documented for use in improving the data management systems that support power system operations.	02/07/2017	Yes	Distribution	1,111	1,111	900	198	1,098	N/A	0	None	0	N/A	Combination of in-house work and pay-for-performance contracts. A RFP was released in third quarter of 2016, with contractor selection completed in 2017.	None to date	RFP	2	Sparta Consulting, dba KPIT	1st	N/A	N/A	No	N/A	The following metrics were identified for this project and evaluated during the course of the pre-commercial demonstration. These metrics are not exhaustive given the pre-commercial demonstration approach for this project. • Safety, Power Quality, and Reliability (Equipment, Electricity System) – The use of machine learning and advanced data analytics can help stakeholders predict the failure of equipment based on current and historical operational data and other data. The following sub-factors could be analyzed with advanced data analytics: o Number of outages, frequency and duration reductions o Forecast accuracy improvement o Public safety improvement o Utility worker safety improvement • Economic Benefits – Advanced data analytics can provide significant economic benefits by helping the identification of failing or aging equipment, before they fail, thereby reducing operational expenditures and planning capital expenditures effectively. The following sub-factors could be affected with advanced data analytics: o Maintain/reduce operations and maintenance costs o Maintain/reduce capital costs	All project activities were completed in 2017. The pre-commercial demonstration included ingestion of several data sources into a data lake, test build of preliminary predictive models for major electric distribution asset management use cases, and visualization development using business intelligence tools to provide insight into the health of various assets on the utility distribution system. Based on the project findings, it is recommended that SDG&E and other utility stakeholders commercially adopt and implement advanced data analytics techniques for effective asset management.
2nd triennial (2015 - 2017)	SDG&E	Monitoring, Communications, and Control Infrastructure for Power System Modernization	Pre-commercial Demonstration	The objective of this project was to demonstrate advanced monitoring, communication and control infrastructure needed to operate an increasingly complex power system infrastructure. In other words, to test system controls to "sort" data and use what is helpful and useful.	01/24/2017	Yes	Distribution	1,305	1,305	1,283	22	1,305	N/A	0	None	0	N/A	Combination of in-house work and pay-for-performance contracts. A RFP was released in third quarter of 2016, with contractor selection completed in 2017.	None to date	RFP	3	GE Grid Solutions	1st	N/A	N/A	No	N/A	The following metrics were identified for this project and evaluated during the course of the pre-commercial demonstration. These metrics are not exhaustive given the pre-commercial demonstration approach for this project. • Identification of barriers or issues resolved that prevented widespread deployment of technology or strategy o Develop standards for communication and interoperability of appliances and equipment connected to the electric grid, including the infrastructure serving the grid (PU Code § 8360) -The EPIC project demonstrated the potential value of OpenFMB in addressing interoperability issues that exist in the electric system today, with multiple vendor technologies/systems unable to interface or interact with each other in a seamless manner. OpenFMB could provide a framework that enables the coexistence of traditional IEDs or devices that operate in a centralized manner with new IEDs or devices (especially DERs) that have the capability to operate in a decentralized manner. o Identification and lowering of unreasonable or unnecessary barriers to adoption of smart grid technologies, practices, and services (PU Code § 8360) - This EPIC project established a potential OpenFMB framework that could be implemented in the secondary layer that sits between the enterprise layer in a utility control center, and the primary layer that sits on multiple devices or equipment in the field. Next generation of IEDs or DERs may provide the necessary communication technology and application framework that enable peer to peer communication between devices and routes the information through the OpenFMB framework to disparate systems in the backend. • Safety, Power Quality, and Reliability (Equipment, Electricity System) - The use of OpenFMB framework to deploy decentralized applications could enable interoperability and improve information sharing between field devices and backend systems. The following sub-factors could be enhanced with the use of OpenFMB: o Reduction in outage numbers, frequency, and duration. o Reduction in system harmonics o Increase in the number if nodes in the power system at monitoring points o Public safety improvement and hazard exposure reduction	All project activities were completed in 2017. The project focus was on pre-commercial demonstration of an Open Field Messaging Bus (Open FMB) for interoperability, peer-to-peer communication, and multiple protocol conversion. A representative test system was constructed, and a total of thirteen use cases were defined to demonstrate the use of OpenFMB for monitoring and control. As a result of this demonstration, it is recommended that work be continued to further define the OpenFMB standard so that it can be successfully utilized in future utility distribution system projects and deployments
2nd triennial (2015 - 2017)	SDG&E	System Operations Development and Advancement	Pre-commercial Demonstration	The objective of this project was to support continued modernization of SDG&E's power system via demonstrations of improved capabilities in system operations. The project demonstrated a systematic process for the realignment of operating practices with advances in technology, software and standards used in the power system. The realignment is broad and addresses system integration issues and technology transfer.	02/15/2017	Yes	Distribution	1,088	1,088	1,056	31	1,088	N/A	0	None	0	N/A	A combination of in-house work and pay-for-performance contracts was used. A RFP was released in third quarter of 2016, with contractor selection completed in 2017.	None to date	RFP	3	Quanta Technology, LLC	1st	N/A	N/A	No	N/A	The following metrics were used to evaluate the project from different perspectives including Project Success Factors, Project Implementation Milestones, and Technical Achievements. • Potential energy and cost savings • Economic benefits • Safety, Power Quality, and Reliability (Equipment, Electricity System • Identification of barriers or issues resolved that prevented widespread deployment of technology or strategy • Effectiveness of information dissemination	All project activities were completed in the year 2017. A PHIL (Power Hardware In the Loop) test system was developed to examine improvements of the distribution system containing modern system component by optimization, using the RAMCO (Regional Aggregation Monitoring and Circuit Optimizers) and LRAM (Local Resource Aggregation and Monitoring). Results from the test system were evaluated and concluded that, the system operated as intended and optimized the distribution system. The recommendation is that stakeholders pursue this system further and commercialize it.
2nd triennial (2015 - 2017)	SDG&E	Integration of Customer Systems into Electric Utility Infrastructure	Pre-commercial Demonstration	The project addressed the evolving gateway between customers and utilities. Specifically, it demonstrated the safe and reliable interoperability of customer systems with the distribution and transmission system and California Independent System Operator (CAISO) operations to improve grid operations and thereby increase ratepayer satisfaction and benefits.	Calendar Year 2017	Yes	Distribution	985	985	922	63	985	N/A	0	None	0	N/A	SDG&E EPIC funding applied to the internal project team work and a pay-for-performance contract.	None to date	Sole Source	N/A	N/A	N/A	N/A	N/A	N/A	N/A	Project tracking metrics included whether the SDG&E/contactor project team met milestones in the project plan. Technical metrics for the demonstration work were identified during performance of the demonstration. Metrics for this project are based on comparing the performance of power system operations when various interoperability solutions are in place with the performance of operations when they are not in place. The commercial adoption of this project will be impacted by the following metrics: o Potential energy and cost savings ▯ The project demonstrated new technologies and analysis methods for monitoring, visualization, and root-cause analysis of distribution systems by using various measurement techniques and data sources and integrating them in one platform to provide a unique monitoring and visualization user experience. This will create significant cost savings through reducing the required nameplate capacity of energy storage and distribution generation facilities due to the enhancement of the operations by providing additional means of awareness about the system behavior. ▯ Avoided procurement and generation costs – Accurate monitoring enables utilities to predict generation costs especially through predicting dynamic events caused by varying characteristics of DER energy productions, loading effect of electric vehicle charging stations, and power electronic apparatus. o Economic Benefits ▯ Operation costs of the system can be significantly reduced by increased awareness and monitoring capability of the system. o Safety, Power Quality, and Reliability • Electric system power flow congestion reduction – Any possible congestion might be diminished due to the improved monitoring, and visibility of the system. Any probable failure, or transient behavior can be properly predicted to avoid possible damage to the personnel, or equipment. • Forecast accuracy improvement – With improved visibility of the system, better forecasting capability is provided for the system, and any undesired behavior can be avoided by properly designing protection systems. • Utility worker safety improvement and hazard exposure reduction – Utility workers safety can be considerably improved by enhanced awareness of distribution assets in the real-time mode. Other obtained safety related improvements include facilitated root cause analysis, operator and engineers training, and assessment of operation and design procedures for new technologies and approaches. • Increase in the number of nodes in the power system with monitoring capability – This project provided more visibility, and situational awareness through increasing number of devices which monitor the system performance. o Identification of barriers or issues resolved that prevented widespread deployment of technology or strategy	All project activities were completed in 2017. The key system capabilities that were successfully demonstrated and validated were: • Monitoring distribution assets in the field (outside of substations) in real-time, based on measurements received from monitoring devices. • Tapping into historical data collected to playback and investigate events over extended periods as selected and required by an operator or an engineer. This approach resolved major issues in previous systems due to lack of proper time synchronization and difficulty of alignment of the data points from various devices. • Providing a set of tools for pre/post event analysis based on various data types and sources; this feature was shown to be very effective for root cause analysis, training of operators and engineers, and assessment of operation and design procedures for new technologies and approaches.
2nd triennial (2015 - 2017)	SDG&E	Collaborative Programs in RD&D Consortia	Pre-commercial Demonstration	The objective of this project was to accomplish highly leveraged demonstration work through collaborative projects in industry R&D consortia. This included information and intelligence leveraging by better informing the project content in EPIC activities with the knowledge of relevant activities occurring in a worldwide sense.	For first module: GIS Surveyors, Inc (08/03/2017, GE Grid Solutions (09/01/2017), Harris Corporation (10/6/2017), Network Mapping (10/12/2017), Price Waterhouse Coopers (09/01/2017) For second module: Navigant Consulting (09/11/2017)	Yes	Distribution	1,561	1,561	1,486	79	1,565	N/A	0	None	0	N/A	SDG&E EPIC funds applied to an internal team and collaborative consortium to define, set up, and execute 2 collaborative pre-commercial demonstration project modules.	None to date	Competitive procurement	6 for module on UAS and 3 for module on customer propensity	For first module: GIS Surveyors, Inc, GE Grid Solutions, Harris Corporation, Network Mapping, Price Waterhouse Coopers For second module: Navigant Consulting	For first module: Top 5 bidders were all selected For second module: Rank 1 was selected	N/A	N/A	Yes (GIS Surveyors, Inc.)	N/A	• The commercial adoption methodologies and tools for estimating propensity for customer adoption of photovoltaics will be impacted by the following metrics. o Potential energy and cost savings - Avoided customer energy use (kWh saved) – The use of tools to estimate customer adoption of PV would lead to understanding the contribution of electric load from PV systems, which in turn will provide the customers with reduced energy usage and economic savings. - Avoided procurement and generation costs – Accurate estimation of customer PV adoption rates would enable utilities to estimate the avoided cost to procure energy from sources that might be inefficient or contribute to environmental pollution. o Environmental benefits -Greenhouse Gas (GHG) emissions reductions – Adoption of PV would lead to reduced emissions from fossil fuel based sources which would have to be used in absence of renewable resources like PV. • The project metrics used to evaluate and test UAS technology and machine learning tools include: o Habitat area disturbance reductions - UAS technologies allow for a remotely operate vehicle to access sensitive habits without impacting the land through vehicular are personnel incursions. The use cases demonstrated a process to capture and analyze electrical facilities, surrounding vegetation and terrain features from an aerial drone. The UAS technology can reduce habitat area disturbance by replacing some required physical inspections with UAS derived inspections. o Wildlife fatality reductions (electrocutions, collisions) - This project module studied the feasibility of combining UAS derived imagery with deep learning analytics to determine the location and condition of avian covers on electrical facilities. The avian covers provide a level of protection against electrocution for birds with large wing spans resting on electrical distribution and transmission poles. Currently the avian covers are assessed by physical inspection taken from ground observation on scheduled maintenance intervals. UAS data capture and associated deep learning analytics could provide increase inspections, improved evaluation of the presence and condition of avian covers resulting in reducing the risk to wildlife. o Utility work safety improvement and hazardous exposure reduction - This project module studied several uses case for utilizing UAS technology and machine learning analytics to remotely observe, measure and catalog electrical facilities and surrounding terrain. The technology and process	Project development on demonstrations through collaborative R&D consortia focused on two modules. All project activities were completed in 2017. For the project module on forecasting customer adoption of photovoltaic (PV), the project team used machine learning to identify several important attributes driving adoption for disadvantaged communities (DAC) and other locations (non-DAC) at the zip code level. Owner occupancy emerged as a key attribute explaining the difference in PV market share. The percentage of owner occupied homes is 50% for DAC zip codes compared to 63% for non-DAC zip codes. It is recommended that SDG&E not commercially adopt these methods and tools at this juncture, without more foundational work being done first. For the module on unmanned aerial systems (UAS) data lifecycle management and deep learning demonstration, the project demonstrated integration with existing and future SDG&E infrastructure, software applications and legacy data sets with the ability to ingest, store, analyze and report on SDG&E assets derived from Geographic Information System (GIS), Power Line Systems – Computer Aided Draft and Design (PLS-CADD), unmanned aircraft system (UAS) collected data and other various sources. Three test cases were demonstrated including equipment identification, vegetation encroachment identification, and cataloging and remote asset management. It is recommended that SDG&E pursue additional evaluation of UAS technology for stakeholder groups within the company that will benefit from the aggregation of various sources of data into a data management platform that also provides advanced analytical capabilities.
								8,059	8,059	7,634	438	8,073																	

ATTACHMENT C

SDG&E EPIC Final Reports for Final Two Project Modules in EPIC-1 and EPIC-2
Appendices 1 and 2

San Diego Gas & Electric Company

EPIC Final Report

Program	**Electric Program Investment Charge (EPIC)**
Administrator	**San Diego Gas & Electric Company®**
Project Number	**EPIC-1, Project 2**
Project Name	**Visualization and Situational Awareness Demonstrations**
Module Name	**Module 2, Additional Use Case Work**
Date	**October 4, 2018**

Attribution

This comprehensive final report documents the work done in this EPIC activity.

The project team for this work included the following individuals, listed alphabetically by last name.

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EXECUTIVE SUMMARY

The initial scope of the EPIC-1, Project 2 was expanded in this added project module to accommodate further demonstration of some applications. This resulted in advanced and integrated versions of the initially developed applications. The results include advanced modelling of Geographic Information Systems (GIS) data model, prediction analytics, and custom applications that support integrated approach to existing methodologies.

Sempra Energy Utilities are utilizing data analytics to keep in par with the growing knowledge and real-time data. With the influx of various modern technologies and sensors to acquire data in real time and 3D (third dimension or altitude), creation of prediction models to aid engineers in field offices, or decision makers, is turning into a reality.

Objectives (EPIC-1, Project 2)

The objective of this demonstration project was to explore how data collected from sensors and devices can be processed, combined, and presented to system operators in a way that enhances grid monitoring and situational awareness. This project addressed how data currently unexploited and separately processed can be integrated and visually presented for strategic use by system operators.

When transformed and presented in a visually integrated manner, this data can be invaluable for utilities to optimize grid operations as well as provide insights into the performance of the overall utility system. This visual framework also provides insights into customers' energy consumption behavior to serve them more effectively, foster energy conservation, and reduce peak demand. The demonstrated specific visualization and situational awareness concepts will be used to help San Diego Gas & Electric Company® (SDG&E®) make better choices on which options should be commercially adopted into the future visualization and situational awareness system.

Scope

The following five use cases, addressing a wide range of SDG&E® business needs within the visualization area, were selected for this project module: (1) Transmission Fault Location Visualization, (2) Load Curtailment Visualization, (3) AMI for Operations, (4) Imagery Management, and (5) GIS Visualization infrastructure modernization.

Approach

The work on implementing each of the use cases included 1) requirements definition for the visualization and situational awareness to be provided by the use case, 2) prototyping the data integration schemes, displays, and algorithms, 3) implementation of a testing plan and 4) data analysis and reporting.

Results

The key element of the solutions for all use cases is the use of GIS data and GIS visualization capabilities to visually and functionally integrate other types of relevant data like SCADA. An emphasis throughout the project was on developing solutions that are responsive, flexible, configurable, and reusable. Therefore, a successful demonstration of these novel solutions not only addressed the current business needs of the five use cases, but also provided a knowledge base and software artifacts that will help SDG&E® find better solutions for its future visualization and situational awareness needs.

The developed solutions collectively cover a truly wide spectrum of SDG&E® business areas, users, business applications, and technology topics that had to be addressed:

- Business Areas: Transmission Operations, Distribution Operations, Emergency Operations Center (EOC), Transmission and Distribution Engineering, Distribution Planning, Maintenance and Construction Services, and Vegetation Management
- Business Functions: Accurate geographic location of transmission faults, geospatial data visualization for situational awareness, load curtailment dashboard for EOC use, and improvements in asset management, operations, and GIS maintenance afforded by new network model, process improvements via automation and geospatial awareness in combination with business intelligence, and empowering end users via enhanced mobility and configurability to match their business needs

Recommendations

Based on the outcomes of pre-production demonstrations in Module 2 of EPIC-1, Project 2, the results for use cases 1 through 3 are being moved into commercial use. Results of use cases 4 and 5 (Imagery Management and GIS Visualization Infrastructure Modernization) have met the objectives set for each of those use cases. However, in both instances, these efforts are initial steps of investigation and additional foundational work is needed, before the cumulative results are ready for commercial use.

Conclusions

- Through the performed work, SDG&E® has demonstrated novel solutions to the selected use cases, and, in the process, has also gained substantial experience in integrating GIS, historical, asset management, and other major SDG&E® computer systems. Both aspects will provide usability well beyond that immediately produced by the project module. The experiences gained through the project, due to the novel nature of what was being demonstrated, should be very useful for SDG&E® and the industry at large. The knowledge is transferrable to the industry at large scale for establishing a general workflow for using these novel solutions.

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Acronyms and Definitions

AF (PI AF)	PI Asset Framework (PI AF) is a single repository for asset-centric models, hierarchies, objects, and equipment (hereafter referred to as elements)[1].
AMI	Advanced Metering Infrastructure
API	Application Program Interface
Basemap	Basemap contains reference geospatial information based on what the cartographer is trying to communicate. Information is added to a basemap by overlaying other information on top of basemap to create a final map.
EOC	Emergency Operations Center
EDO	Electric Distribution Operations
eGIS	Enterprise GIS
ETL	A database usage process to Extract, Transform, and Load information. Typically associated with Data Warehouse activities.
Feature (on a map)	Individual item on a map
Feature layer	A feature layer is a grouping of similar geographic features (e.g., electric circuits, poles, buildings, parcels, cities, roads, and earthquake epicenters). Features can be points, lines, or polygons (areas). Feature layers are used for visualizing data on top of basemaps. In the context of integration with PI, feature layer is a collection of AF elements based on the same AF template.
Feature service	A collection of related feature layers. Feature services are managed by Esri ArcGIS. Real time updates of feature services are done via Esri ArcGIS GeoEvent Processor (new name: ArcGIS GeoEvent Extension for Server)
GIS	Geographic Information System
GPU	Graphics Processing Unit
HTTP; HTTPS	Hyper Text Transfer Protocol. HTTPS is over Secure Sockets Layer (SSL) to ensure secure data transfer in transit.
ID	Identifier
IED	Intelligent Electronic Device
IIS	Internet Information Services (formerly Server), an extensible web server created by Microsoft
IoT	Internet of Things
JSON	JavaScript Object Notation

[1] PI AF - Overview - OSIsoft Tech Support, https://techsupport.osisoft.com/Products/PI-Server/PI-AF/Overview/

Lat/Long	Latitude/Longitude of a geographical point
LiDAR	Light Detection And Ranging (also called LIDAR, LiDAR, and LADAR) is a surveying method that measures distance to a target by illuminating that target with a pulsed laser light and measuring the reflected pulses with a sensor. Differences in laser return times and wavelengths can then be used to make digital 3D-representations of the target
LMP	Locational Marginal Price
NMS	Network Management System (SDG&E®)
PNode (pnode)	CAISO pricing node, the location in the network at which LMPs are provided
PV	Photovoltaic (solar) cells for producing electricity from Sun energy
RT	Real Time
SOM	Summary Operating Map
SSL	Secure Sockets Layer. It uses encryption for data in transit
UC	Use Case
UI	User Interface
Widget	An element of a graphical user interface (GUI) that displays information or provides a specific way for a user to interact with the operating system or an application

1 INTRODUCTION

This report documents the demonstration work and results for Module 2 of SDG&E's EPIC-1, Project 2, Visualization and Situational Awareness Demonstration, describes key lessons learned, and identifies opportunities to provide additional value to SDG&E®and other users in the future by leveraging the insights and the specific solution patterns of this project.

Decades ago, *situation awareness* (SA) was formally defined by Endsley[2] in terms of three concepts - perception, comprehension, and projection: "SA is the perception of the elements in the environment within a volume of time and space, the comprehension of their meaning, and the projection of their status in the near future". While tweaks to this definition have been suggested since, the essential elements still remain, which is that, for situational awareness, one needs to consider perceptions within the contexts of both time and space. To do this, one has to be able to readily understand the information contained in the observations, and from these two and other domain knowledge, project the status in the near future.

In the power system industry, the systems that manage and present geo-spatial and other kinds of slowly changing data (e.g., spatial data) have existed largely in separate silos from the systems that deal with operational, time-varying data. Yet, both kinds of data are essential for comprehension of the true state of the system at a point in time, especially during emergencies, and for assessing a progression of that state into the near future.

In the case of SDG&E®, geo-spatial data is handled by Esri ArcGIS, and operational data eventually flows into OSISoft PI Data Historians. Each of the systems is very powerful in its own domain and is constantly being updated and extended with new features for analysis and presentation of results. The combination of the capabilities of the two brings the situational awareness contributions that neither of the two systems can achieve alone. For this reason, several of the activities in this task are centered on the technologies used to merge the information of the two aforementioned (and other) systems (i.e., geospatial and time series data), as necessary to fulfill specific SDG&E® business needs.

The third major component used in this project is Power BI from Microsoft. Out of the box, this tool brings Excel-like capabilities for end users to programmatically, or through a Graphical User Interface (GUI), configure the data sources to use, perform data analytics on the collected data, and select desired built-in or newly developed visualization widgets for display. During this project, SDG&E® has developed a Java programming-based functionality to incorporate Power BI widgets within Esri geospatial features, so the users can see and interact with the map or Power BI widgets in a coordinated fashion. For example, a selection of an element in a Power BI table highlights the corresponding element on a geospatial map, and vice versa.

A brief overview of each of these commercial building blocks is presented in the appendix.

[2] Mica R. Endsley, "Toward a theory of situation awareness in dynamic systems," Human Factors, 1995, Vol 37, pp. 32-64

1.1 Project Objectives

The objectives of the EPIC Visualization and Situational Awareness Demonstration project were to:

- Examine how data currently unexploited and separately processed can be integrated and visually presented for strategic use by system operators
- Demonstrate how data collected from sensors and devices can be processed, combined, and presented to system operators in a way that enhances utility system monitoring and situational awareness. The project was divided into two modules. The first module was completed in 2017, and its final report is available on www.sdge.com/epic. This document is the final report for the second module.

1.2 Scope of Work- Use Cases

The second project module added to the use case work of the first module. The second module was focused on the following five use cases:

1. Transmission Fault Location Visualization
2. Load Curtailment Visualization
3. Advanced Metering Infrastructure (AMI) for Operation Visualization
4. Imagery Management
5. GIS Visualization Infrastructure Modernization.

1.3 Main Visualization Components

Use cases were implemented by combining functionality of core components from Esri, OSISoft, and Microsoft with third party applications and custom applications developed by the SDG&E® team. An overview of the SDG&E® components that comprise the demonstration system, plus other interacting systems and components in Figure 1-1. The GIS (Geographic Information Systems) components are on the left side of the figure; OSISoft PI components are on the right side; Power BI is in the cloud in the middle of the figure; and Smart Grid components, T&D Operations, and AMI components complement the picture. The main end-user interactions are through the web portal (in the middle of the figure), while the developers have local access at various points throughout the system.

A brief overview of functionality of the core commercial components is provided in the appendix; the programming methodology used by SDG&E®, developed to only achieve EPIC project use cases objectives, is discussed in the context of specific solutions for the various use cases.

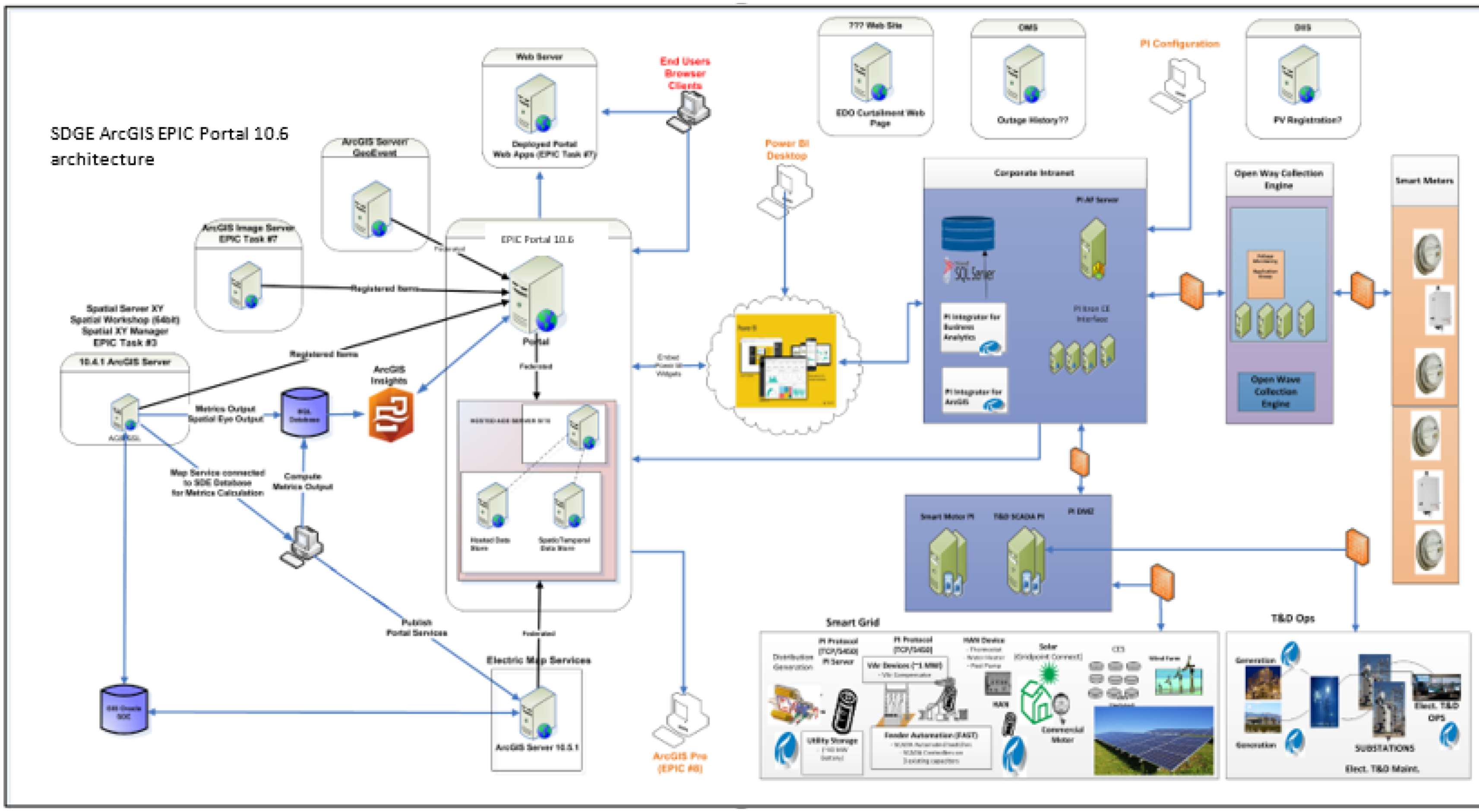


Figure 1-1. Main Components of Visualization and Situational Awareness Demonstration

2 USE CASES FOR DEMONSTRATION

This project module was comprised of five use cases covering a broad range of SDG&E® smart grid business needs. The description of use cases in this section consists of the following:

- Background
- Objectives
- Users
- Solution Approach, Solution Components, and Work Flow
- Results
- Observations, Challenges, and Lessons Learned

2.1 Transmission Fault Location Visualization (UC 1)

2.1.1 Background

At SDG&E®, substation relays are equipped with a function to compute a linear distance (i.e., a distance from the substation housing the relay along the line) to the line fault. When a fault occurs, relays detect it and compute the linear distance. This information eventually flows into the PI archiving system, from which an existing program called *PI Notification* sends text e-mails to relevant users with information about the fault.

At SDG&E®, in order to prepare for unexpected fault shifts, substation relays are equipped with a function for computing linear distance (i.e., a distance from the substation housing the relay along the line) to the fault line. When a fault occurs, relays detect it and computer the linear distance. This information eventually flows into the PI archiving system (PI Data Historian), from which an existing program called *PI Notification* sends text e-mails to relevant users with information about the fault.

The intent of Use Case 1 was to demonstrate the Transmission Fault Location application that will enhance situational awareness about the fault by: (1) extending the e-mail message with a link to a specific web page on the ArcGIS Portal; (2) developing the functionality to generate the target web page and show a geospatial map on the page with the electric circuits and fault indicators at the exact location of the fault; and (3) showing any other geospatial layers, such as weather, fire, earthquake, etc., that may be available in the GIS system.

2.1.2 Objective

The objective of this use case was to demonstrate the ability for end users to see fault locations and associated data on a geographical map within ArcGIS Portal.

2.1.3 Users

- Transmission operation group (Grid Operations)
- Maintenance crew - Kearny Maintenance and Ops
- System protection - System Protection and Control Engineering (SPACE)

2.1.4 Solution Approach, Solution Components, and Work Flow

Components involved in the solution:

- PI Notification: sends e-mails to users
- PI Integrator: pushes dynamic data updates to update maps
- ArcGIS Geo Processing: a service to convert linear distance to a fault obtained from PI to the latitude and longitude (Lat/Long) of the fault by using the geometry of the asset in the geospatial database
- GeoPortal: displays geospatial maps with electric circuit overlays, along with fault indicator(s) on the affected electric circuits, and any other layers, such as weather, fire, lightning strikes, etc.

The technical solution uses two cooperating processes. The first is supported by an SDG&E® custom program and by components from both the PI system and Esri GIS system. This is an event-driven process, with the event being an arrival of new fault data to PI Data Historian. When this event triggers, the custom program retrieves the description of the fault from PI Data Historian (tieline, substation, and the linear distance from the substation along the tieline) and invokes an ArcGIS Geo Processing service called ArcGIS Linear Referencing Geoprocessing service to compute the Latitude/Longitude (Lat/Long) of the faulted location. After receiving the results, the custom program updates PI Data Historian with this Lat/Long data. The second process is based on leveraging the "out of the box" functionality of PI Integrator for Esri ArcGIS and is shown in a simplified form in Figure 2-1.

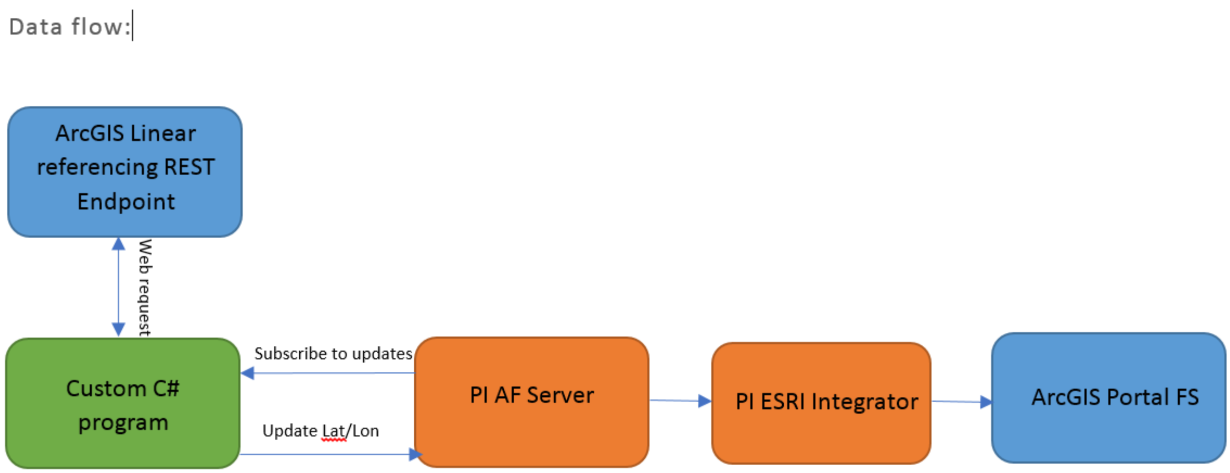


Figure 2-1. Transmission Fault Location Data Flow Diagram

The process consists of the following steps:

1. The PI Integrator for Esri ArcGIS publishes the PI Fault Distance template to ArcGIS Portal, where it gets registered as a feature service, with its own URL
2. When the feature layer is added to a map, the ArcGIS client makes a periodic request (at pre-configured intervals, e.g., every 2 seconds) to the registered PI Esri integrator URL for the Fault Distance layer data
3. The PI Integrator for Esri ArcGIS then requests the data from the PI system, specifically from the Asset Framework (AF) Server (if it is not cached) and returns the data to the client

4. The requested features are drawn on the map according to the retrieved data, including redrawing of the fault locations based on the latest retrieved Lat/Long data

The mechanism for dynamic map feature updates described above is the same for any use case that uses PI Integrator for Esri ArcGIS. The only differences are which of the PI data templates (such as the fault Lat/Long in this use case) drive the display.

A JavaScript Object Notation (JSON) code snippet illustrating a request from the ArcGIS of a Linear Referencing endpoint is shown in Figure 2-2.

The ArcGIS Linear referencing service automatically updates the computed Lat/Long result in PI (Figure 2-3).

Figure 2-2. Request from ArcGIS Geoprocessing Service

Filter

Name	Value
BreakerStatus	--
CircuitBreaker	0
CoreSightLink	0
FaultDistance	3 mi
IsBeginning	False
Latitude	-116.8695068359375
Longitude	32.833930969238281
MW	0 MW
TieLine	
Tieline Length	43435.660142
TieLineID	678

Figure 2-3. PI Fault Location Template – Highlighted Item Updated by ArcGIS Linear referencing service

2.1.5 Results

2.1.5.1 Representative Results

Figure 2-4 shows two fault locations. In this example, the user has clicked the pin for the latter fault, and a popup display provides more details, including name (which is the name of a relay in PI comprised of a tieline ID, and a substation ID), circuit name, fault distance, and the exact coordinates of the fault.

However, at this level of detail, it is not possible to say if there are multiple circuits in the affected area. By zooming in (Figure 2-6), it can be seen that there are actually several circuits (at different voltage levels), and the Fault Pin pinpoints exactly the affected circuit (matching the description in the popup table of the previous figure).

Incidentally, these two figures also illustrate the useful automatic decluttering capability of the GIS software.

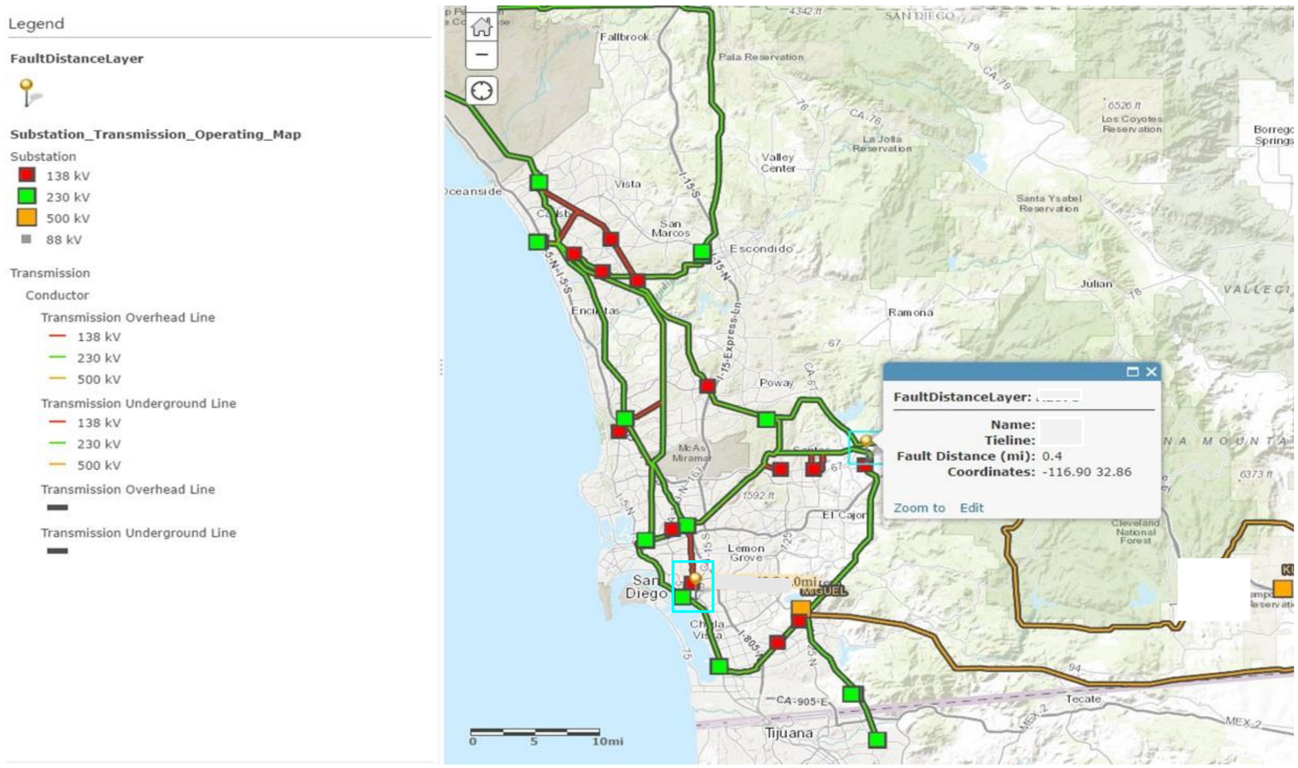
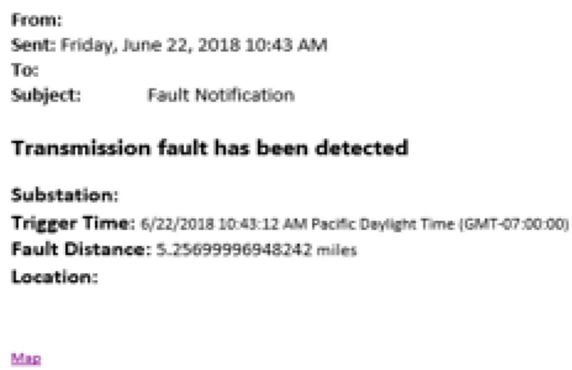


Figure 2-4. Map with Fault Location



From:
Sent: Friday, June 22, 2018 10:43 AM
To:
Subject: Fault Notification

Transmission fault has been detected

Substation:
Trigger Time: 6/22/2018 10:43:12 AM Pacific Daylight Time (GMT-07:00:00)
Fault Distance: 5.25699996948242 miles
Location:

Map

Figure 2-5. Email generated after fault detection

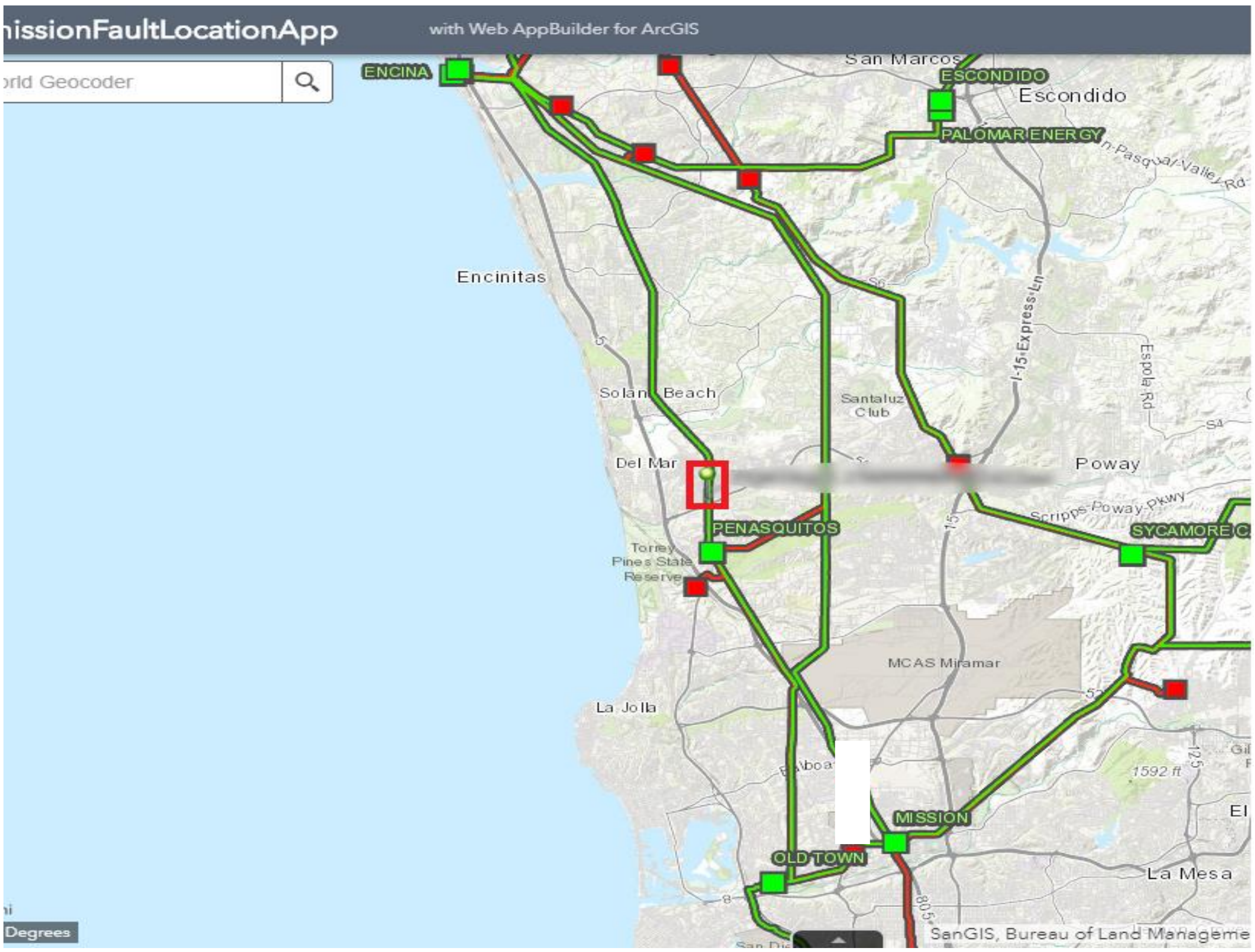


Figure 2-6. Map Detail with Fault Location (indicated by a pin)

2.1.6 Observations, Challenges, and Lessons Learned

<u>Challenges and Resolutions</u>

- SDG&E® may eventually want to use a double-ended fault algorithm to provide even more accuracy
- Handling of faults on tapped lines is a challenge, especially when the single ended fault location algorithm is used – as for some fault locations, it is ambiguous if the fault has occurred on the main trunk or a tapped line. The work on overcoming this challenge is still in progress, with an expectation that the use of a double-ended fault algorithm will help in the resolution. Nevertheless, in the vast majority of fault location cases, the existing solution is fully functional.
- Creation of the reference layer of electrical circuits (from which the fault x-y coordinates and the x-y coordinates of the circuits themselves are derived): the GIS database may have a line asset represented as multiple line segments, each with a “from” and a “to” side and with a significant number of other attributes. ArcGIS has a service called ArcGIS Geoprocessing Service to convert a linear distance (along an asset) to the x-y coordinates of the point at the end of the linear distance. However, this service is time consuming when there are many segments to peruse. To increase the ArcGIS Geoprocessing Service performance, it was necessary to perform an upfront work to appropriately concatenate line segments and create a new, simplified, composite line that always spans two substations. The line ID of this composite line needs to be provided to PI, where it serves as a key for linking the x-y information of the fault computed by ArcGIS Geoprocessing Service with operational data from PI. Any time there is a reconfiguration of a physical line, this process of so-called “digitizing” (i.e., updating of the composite line) needs to be repeated (only the very first time and after a reconfiguration). The initial effort to “digitize” all the lines, given that all 69-kV and higher voltage lines are included, was substantial. Once initially completed, an incremental effort to update after a reconfiguration is much less intensive, as such events are relatively infrequent, and the scope is much smaller (as it involves only the reconfigured lines).

<u>Recommendations</u>

- The labor to create the initial reference layers of electric circuits is significant and should be planned for in advance
- A process is needed to “re-digitize” lines any time there is a reconfiguration, or to digitize new lines, with an associated process to reflect the changes, if any, of the line ID in PI.
- Enhancing the User Interface (UI) of the web page and overall design could improve end user experience.

2.2 Load Curtailment Visualization (UC 2)

2.2.1 Background

Currently, SDG&E® Electric Distributions Operations (EDO) updates load curtailment plans via a spreadsheet (shown later in Figure 2-8). The spreadsheet is posted on the EDO Website.

The spreadsheet shows the current total MegaWatt (MW) request for load shedding from CAISO, the amount of load already shed, as well as a list of circuits in groups according to the order in which they need to be opened to affect the load shedding. The groups are labeled Run 1, Run 2, and so on, and are arranged so that the circuits in Run 1 are opened first. Then, if there is need for more load shedding, the circuits of Run 2 are opened, and so forth. The coloring of circuits is chosen to reflect the likelihood of load shedding, with red designating the first group of circuits to open.

The information in the spreadsheet is a combination of asset names and real-time load data. The intent of this use case is to display the same tabular (i.e., the spreadsheet) information but through a geospatial map, with visual cues identifying the order in which the circuits are to be opened. Examples in the results section illustrate additional options and benefits provided by the geospatial displays that in total should provide a better visual sense of when and where the load is being shed. This aspect of being able to quickly grasp the extent and location of load shedding may be very important, taking into account that load shedding is seldom required, but when it is, it is usually associated with emergency situations during which effective situation assessment is paramount.

2.2.2 Objective

The objective of Use Case 2 was to demonstrate an ArcGIS Portal map to visualize the current SDG&E® load curtailment plan.

2.2.3 Users

- Emergency Operations Center (EOC) personnel, during emergencies
- Distribution Operations

2.2.4 Solution Approach, Solution Components, and Work Flow

Components:

- Internal SDG&E® Web site: the current load curtailment plan published to the site (existing functionality)
- Custom Python program periodically “scrapes” EDO Curtailment Webpage and writes the parsed curtailment results to PI
- PI Integrator for Esri ArcGIS publishes Curtailment Template to GIS Portal
- Current values of the map’s dynamic widgets (e.g., current total loads on each of the circuits marked for curtailment are updated through periodic queries from Esri portal client via PI Esri Integrator to the PI Data Historian); this can be seen later in Figure 2-8
- Esri Operations Dashboard for ArcGIS: a dashboard with the Load Curtailment map as one of its elements (example shown later in Figure 2-10)

A simplified diagram of the major data flows is shown in Figure 2-7.

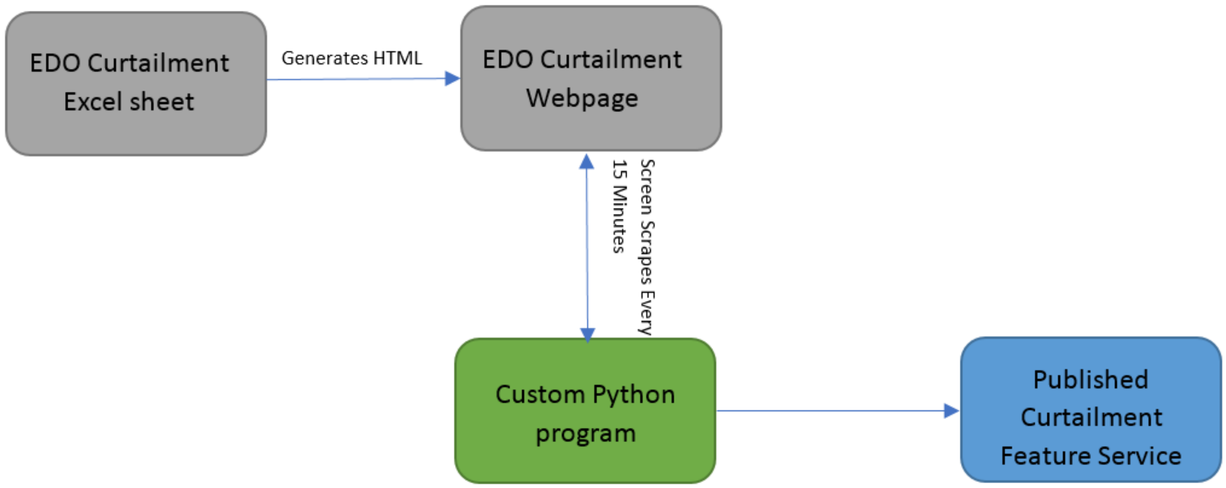


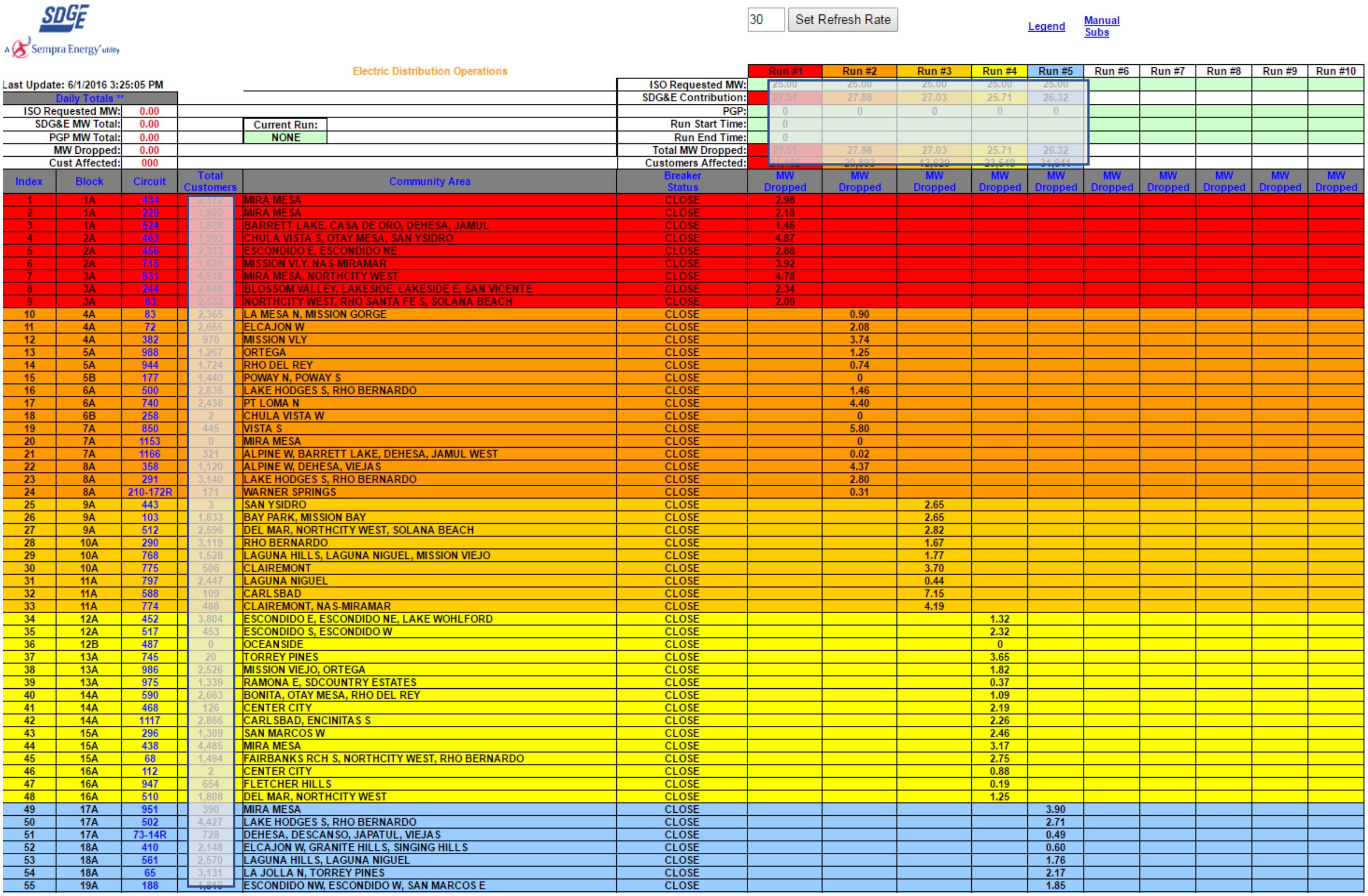
Figure 2-7. Load Curtailment Data Flow Diagram

An example of an EDO HTML Load Curtailment Page (the source of data for this use case) is shown in Figure 2-8.

An ArcGIS Portal map of load curtailment is shown in Figure 2-9. The legend on the left shows use of color to convey the status of circuits with respect to load shedding (e.g., previously or currently curtailed, early restored, or one of the exempt circuits); or it is a circuit in the first group to be curtailed (red), or in one of the later rounds (orange, light orange, yellow, etc.).

The Curtailment layer has every circuit, and each circuit has an associated Status field. When the Status field is blank, the corresponding circuit is filtered out from the display.

The map is made into a dashboard using the program Esri Operations Dashboard (Figure 2-10). Multiple circuits can be selected by interactively encircling a region of interest. The widget on the lower right will then summarize the total MW dropped from the selected circuits. The list on the left side contains only the circuits that are due for curtailment.



Daily Totals **	
ISO Requested MW:	0.00
SDG&E MW Total:	0.00
PGP MW Total:	0.00
MW Dropped:	0.00
Cust Affected:	000

	Run #1	Run #2	Run #3	Run #4	Run #5	Run #6	Run #7	Run #8	Run #9	Run #10
ISO Requested MW:	25.00	25.00	25.00	25.00	25.00					
SDG&E Contribution:	27.51	27.88	27.03	25.71	26.32					
PGP:	0	0	0	0	0					
Run Start Time:	0									
Run End Time:	0									
Total MW Dropped:	27.51	27.88	27.03	25.71	26.32					
Customers Affected:	21,465	20,893	12,629	23,549	31,641					

Index	Block	Circuit	Total Customers	Community Area	Breaker Status	Run #1 MW Dropped	Run #2 MW Dropped	Run #3 MW Dropped	Run #4 MW Dropped	Run #5 MW Dropped	Run #6 MW Dropped	Run #7 MW Dropped	Run #8 MW Dropped	Run #9 MW Dropped	Run #10 MW Dropped
1	1A	434	2,172	MIRA MESA	CLOSE	2.98									
2	1A	229	1,820	MIRA MESA	CLOSE	2.18									
3	1A	524	1,838	BARRETT LAKE, CASA DE ORO, DEHESA, JAMUL	CLOSE	1.46									
4	2A	463	1,993	CHULA VISTA S, OTAY MESA, SAN YSIDRO	CLOSE	4.87									
5	2A	456	2,313	ESCONDIDO E, ESCONDIDO NE	CLOSE	2.88									
6	2A	715	1,639	MISSION VLY, NAS-MIRAMAR	CLOSE	3.92									
7	3A	831	4,510	MIRA MESA, NORTHCITY WEST	CLOSE	4.78									
8	3A	244	2,648	BLOSSOM VALLEY, LAKESIDE, LAKESIDE E, SAN VICENTE	CLOSE	2.34									
9	3A	63	2,532	NORTHCITY WEST, RHO SANTA FE S, SOLANA BEACH	CLOSE	2.09									
10	4A	83	2,365	LA MESA N, MISSION GORGE	CLOSE		0.90								
11	4A	72	2,655	ELCAJON W	CLOSE		2.08								
12	4A	382	970	MISSION VLY	CLOSE		3.74								
13	5A	988	1,267	ORTEGA	CLOSE		1.25								
14	5A	944	1,724	RHO DEL REY	CLOSE		0.74								
15	5B	177	1,440	POWAY N, POWAY S	CLOSE		0								
16	6A	500	2,835	LAKE HODGES S, RHO BERNARDO	CLOSE		1.46								
17	6A	740	2,438	PT LOMA N	CLOSE		4.40								
18	6B	258	2	CHULA VISTA W	CLOSE		0								
19	7A	850	445	VISTA S	CLOSE		5.80								
20	7A	1153	0	MIRA MESA	CLOSE		0								
21	7A	1166	321	ALPINE W, BARRETT LAKE, DEHESA, JAMUL WEST	CLOSE		0.02								
22	8A	358	1,120	ALPINE W, DEHESA, VIEJAS	CLOSE		4.37								
23	8A	291	3,140	LAKE HODGES S, RHO BERNARDO	CLOSE		2.80								
24	8A	210-172R	171	WARNER SPRINGS	CLOSE		0.31								
25	9A	443	3	SAN YSIDRO	CLOSE			2.65							
26	9A	103	1,833	BAY PARK, MISSION BAY	CLOSE			2.65							
27	9A	512	2,596	DEL MAR, NORTHCITY WEST, SOLANA BEACH	CLOSE			2.82							
28	10A	290	3,119	RHO BERNARDO	CLOSE			1.67							
29	10A	768	1,528	LAGUNA HILLS, LAGUNA NIGUEL, MISSION VIEJO	CLOSE			1.77							
30	10A	775	506	CLAIREMONT	CLOSE			3.70							
31	11A	797	2,447	LAGUNA NIGUEL	CLOSE			0.44							
32	11A	588	109	CARLSBAD	CLOSE			7.15							
33	11A	774	488	CLAIREMONT, NAS-MIRAMAR	CLOSE			4.19							
34	12A	452	3,804	ESCONDIDO E, ESCONDIDO NE, LAKE WOHLFORD	CLOSE				1.32						
35	12A	517	453	ESCONDIDO S, ESCONDIDO W	CLOSE				2.32						
36	12B	487	0	OCEANSIDE	CLOSE				0						
37	13A	745	20	TORREY PINES	CLOSE				3.65						
38	13A	986	2,526	MISSION VIEJO, ORTEGA	CLOSE				1.82						
39	13A	975	1,339	RAMONA E, SDCOUNTRY ESTATES	CLOSE				0.37						
40	14A	590	2,663	BONITA, OTAY MESA, RHO DEL REY	CLOSE				1.09						
41	14A	468	126	CENTER CITY	CLOSE				2.19						
42	14A	1117	2,866	CARLSBAD, ENCINITAS S	CLOSE				2.26						
43	15A	296	1,309	SAN MARCOS W	CLOSE				2.46						
44	15A	438	4,485	MIRA MESA	CLOSE				3.17						
45	15A	68	1,494	FAIRBANKS RCH S, NORTHCITY WEST, RHO BERNARDO	CLOSE				2.75						
46	16A	112	2	CENTER CITY	CLOSE				0.88						
47	16A	947	654	FLETCHER HILLS	CLOSE				0.19						
48	16A	510	1,808	DEL MAR, NORTHCITY WEST	CLOSE				1.25						
49	17A	951	390	MIRA MESA	CLOSE					3.90					
50	17A	502	4,427	LAKE HODGES S, RHO BERNARDO	CLOSE					2.71					
51	17A	73-14R	728	DEHESA, DESCANSO, JAPATUL, VIEJAS	CLOSE					0.49					
52	18A	410	2,148	ELCAJON W, GRANITE HILLS, SINGING HILLS	CLOSE					0.60					
53	18A	561	2,570	LAGUNA HILLS, LAGUNA NIGUEL	CLOSE					1.76					
54	18A	65	3,131	LA JOLLA N, TORREY PINES	CLOSE					2.17					
55	19A	188	[illegible]	ESCONDIDO NW, ESCONDIDO W, SAN MARCOS E	CLOSE					1.85					

Figure 2-8. Example EDO HTML Load Curtailment Page

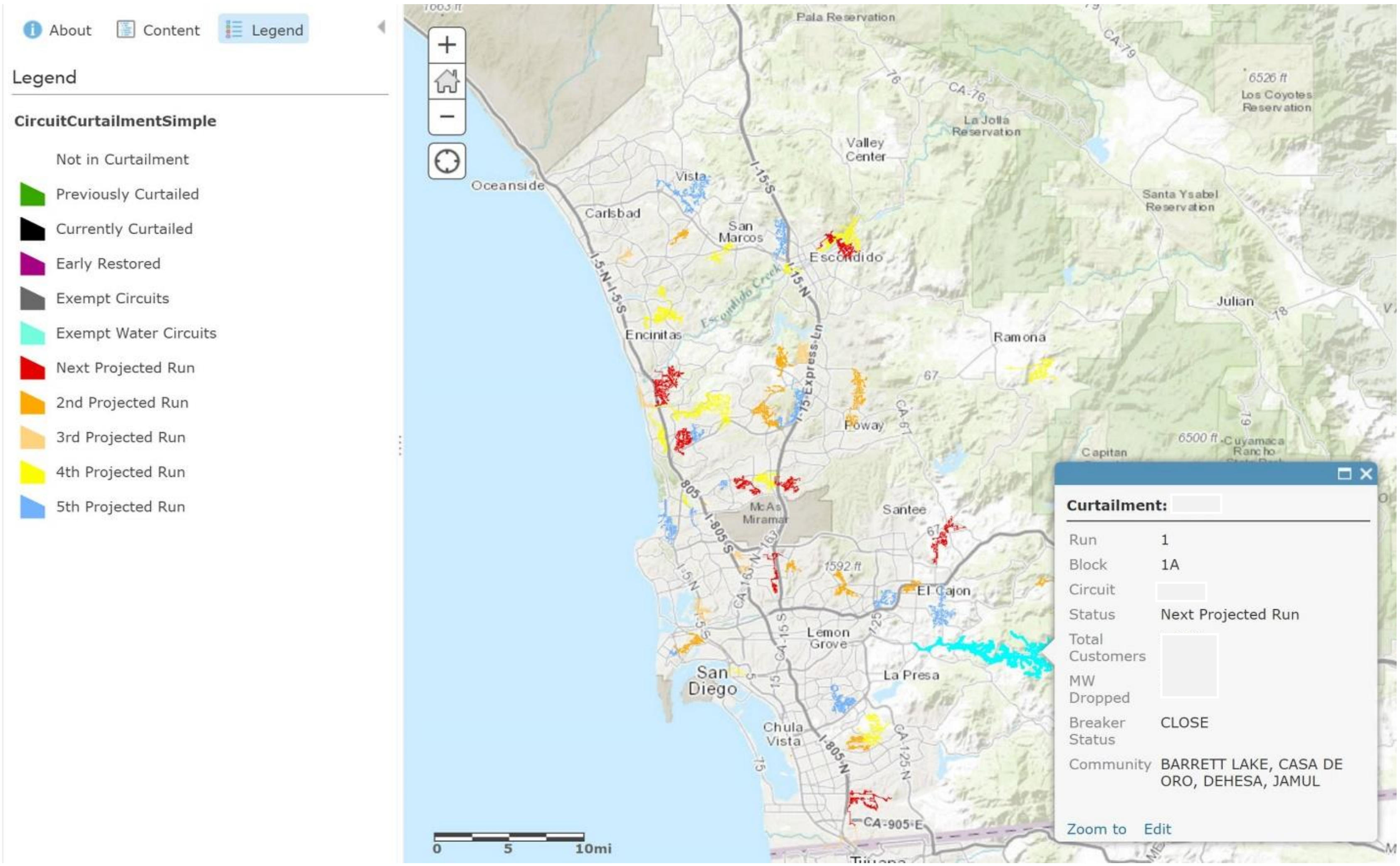


Figure 2-9. Example Load Curtailment Map

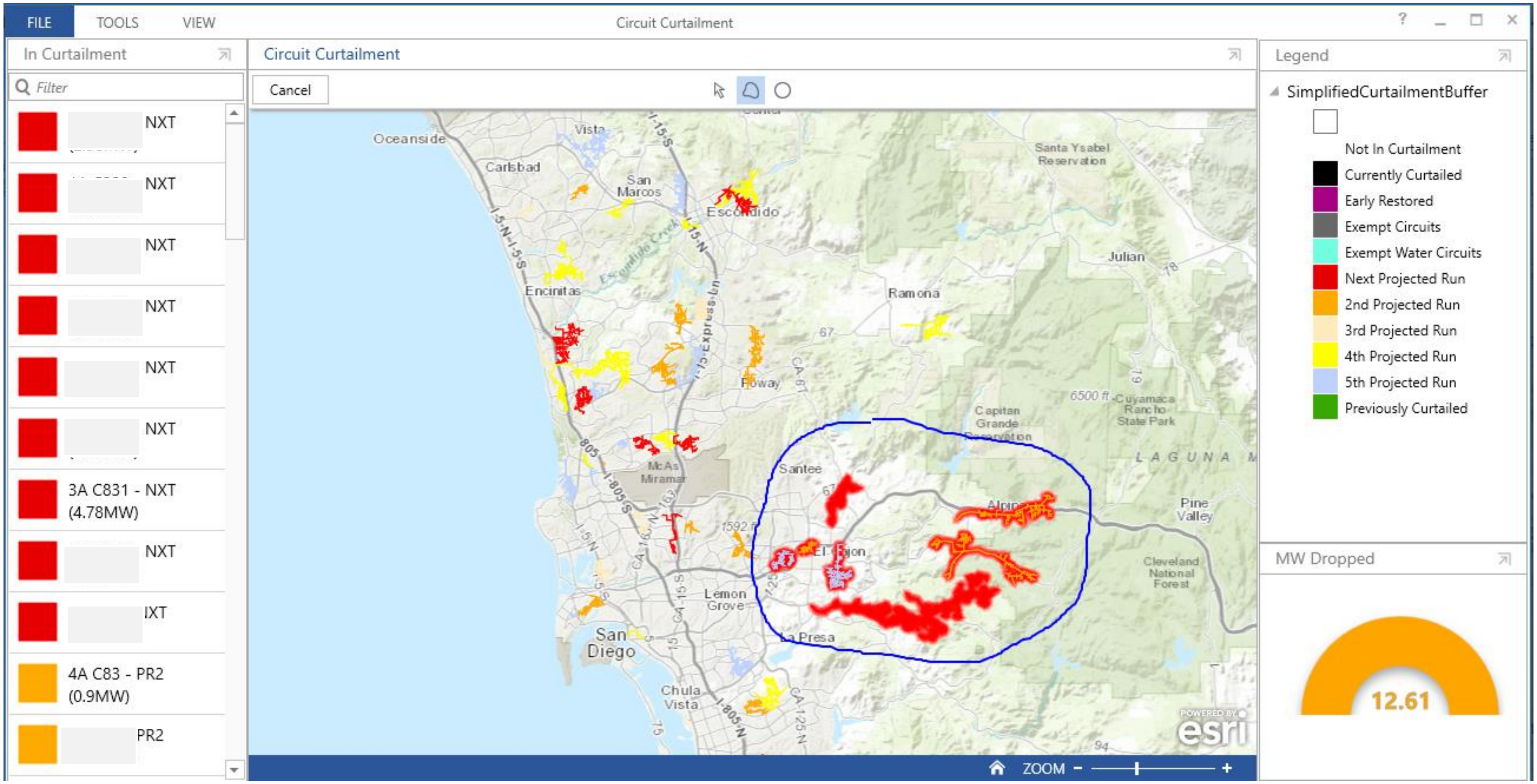


Figure 2-10. Load Curtailment Dashboard

This dashboard example illustrates how the end users are empowered by this solution – they can merely draw a boundary around a region of interest, and the display will automatically update with the total MW to be dropped within the region based on the actual load at the time of inquiry. Note that the legend adapts to the selected region of interest. This example also illustrates how the solution enables a user to get information of interest very quickly and in an intuitive way.

2.2.5 Results

2.2.5.1 Features

- Geospatial maps show the circuits for load shedding (either just finished, in progress, or planned)
- Color coding used to indicate both the (near) real time and the planned load shedding status
- Automatic decluttering of circuits that are not involved in load shedding
- Built in capabilities of GIS system can be leveraged to quickly create load shedding dashboard, which further extend usability of the displays by empowering users to make ad-hoc inquiries about load shedding amounts in any region of interest

2.2.5.2 Representative Results

The figures shown above illustrate the basic functionality and features of the load shedding use case.

2.2.6 Observations, Challenges, and Lessons Learned

Challenges and Resolutions

- In the absence of available Application Program Interfaces (API) to interact with the SDG&E® Web legacy system where the load curtailment schedules are posted, an interface to this system was implemented by scraping the site's web pages. Such technology is inferior to an interface based on a dedicated API.
- The electrical line circuits' information used for GIS visualization is rebuilt nightly to ensure the circuits' layer is a good reference for all the uses in need of this information. A coordination with PI data (at the level of line ID updates where new lines are created, or existing lines are retired) is also required any time the electrical circuit layout and connectivity change.
- Initially, the circuit layer visualization on the map was very slow. Significant improvements were made by using the Esri "generalization" tool to remove extreme details such as many vertices. The result is circuit representation without a visually perceptible loss of information yet enabling a substantial speedup of rendering. For example, it originally took upward of 20 seconds to render the electric circuit layers; it now takes a fraction of a second. When zooming in, the circuit layout is still sufficiently accurate.

Recommendations

- From a development perspective, it is recommended to replace scraping of web pages with an interface via a dedicated API
- From a usage standpoint, the commercial adoption team will seek further feedback from the managers of EOC after a planned demonstration of the function is presented to them in the near future

2.3 AMI for Operations (UC 3)

2.3.1 Background

A widespread availability of AMI data provides an opportunity to get a clearer real-time picture of the voltage situation across the SDG&E® network. The purpose of Use Case 3 is to overlay the AMI and SCADA voltage data onto a GIS map containing the electrical circuit topology and to create a heat map that shows the voltage swell and sag data. This visualization capability is expected to assist during emergency operations under various scenarios, such as the following:

- Storm
- Red Flags (e.g., High Winds –such as “Santa Ana Winds”)
- Earthquake
- Wildfire

After the fact, the historical playback capability should allow analysis of voltage behavior during different situations and, thus, provide a valuable insight about the need for system upgrades.

2.3.2 Objective

The objective of this demonstration was to overlay the AMI and SCADA voltage data onto a GIS map with circuit topology and create a heat map that shows the voltage swell and sag data on the GIS map.

2.3.3 Users

- Electric T&D Engineering
- Electric Distribution Planning
- Electric Distribution Operation

2.3.4 Solution Approach, Solution Components, and Work Flow

Solution components:

- Smart Meter PI
- DMZ PI
- Power BI
- PI Event Frame: detect voltage changes that constitute an event (e.g., voltage above 1.05%)
- ArcGIS picks up 10 years’ worth of the events captured by PI Event frame
- Esri Web AppBuilder to integrate Power BI widgets and other customizations for GIS Portal
- GIS Portal

An ability to show the substation SCADA data and the field devices’ power quality data as map layers is created by the PI Integrator for Esri ArcGIS, and custom components indicated in green in Figure 2-11.

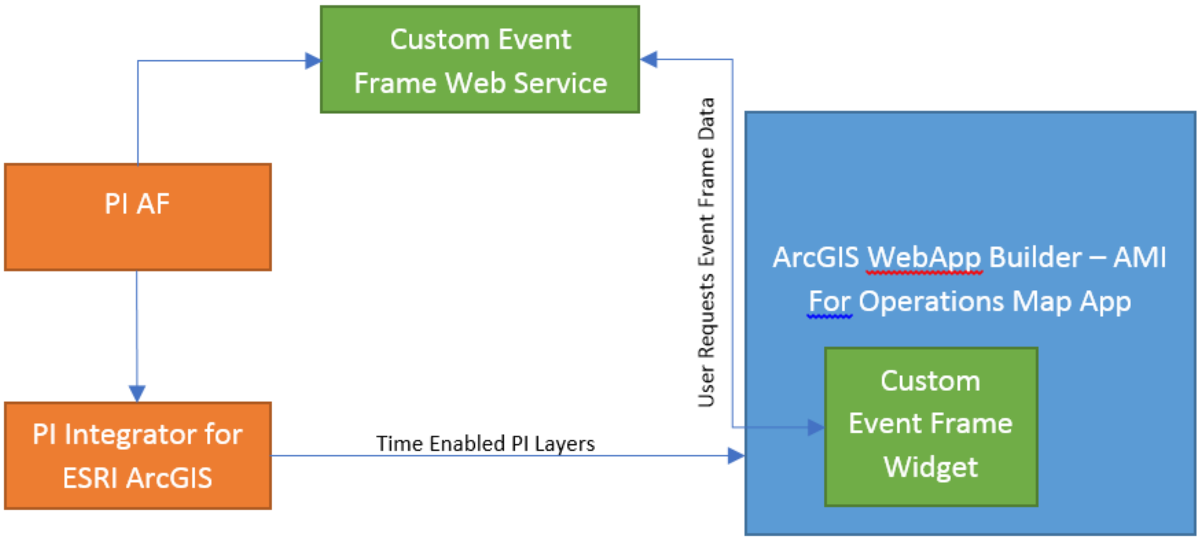


Figure 2-11. AMI for Operations Data Flow Diagram

2.3.5 Results

2.3.5.1 Features

- Voltage for primary distribution circuits with visual indicator % of nominal voltage and Visualization display for additional parameters available in Historian (PF, THD, voltage & load unbalance, etc.).
- Trending granular distribution circuit voltage analysis based on AMI data with the intent to identify possible future problem areas.
- Visualizations for other Intelligent Electronic Device (IED) data beyond typical SCADA such as microprocessor-controlled circuit breakers, relays, transformers, regulators, and capacitors. The System Protection and Control group can provide detail.
- Visualizations for emergency operations various scenarios:
- Storm, Red Flag (Wind – Santa Ana), Earthquake, Wildfire

2.3.5.2 Representative Results

Figure 2-12. through Figure 2-15. illustrate (self-explanatory) custom widgets for configuring various display attributes for this use case.

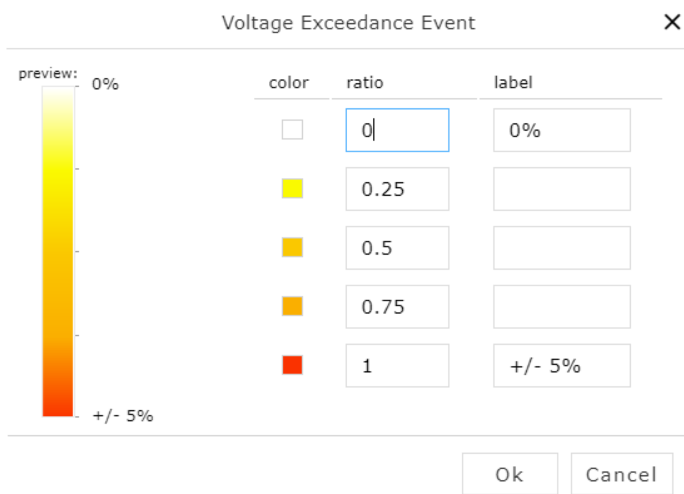


Figure 2-12. Custom Widget: Customizable Heat Map Colors

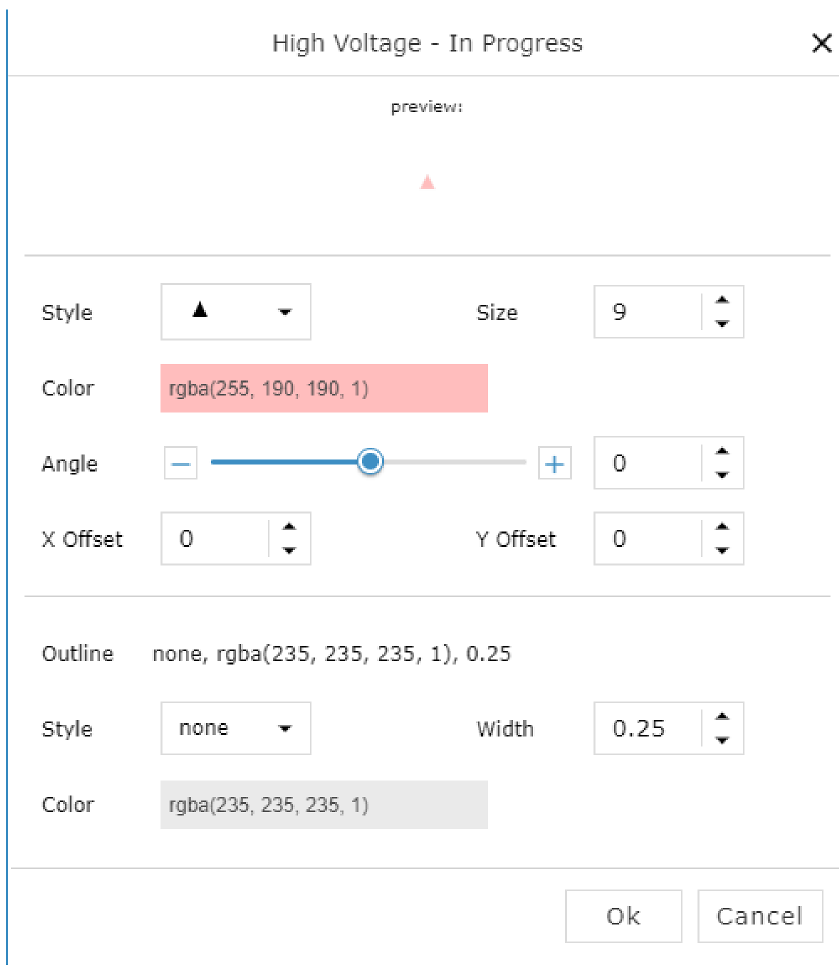


Figure 2-13. Custom Widget: Customizable Symbols

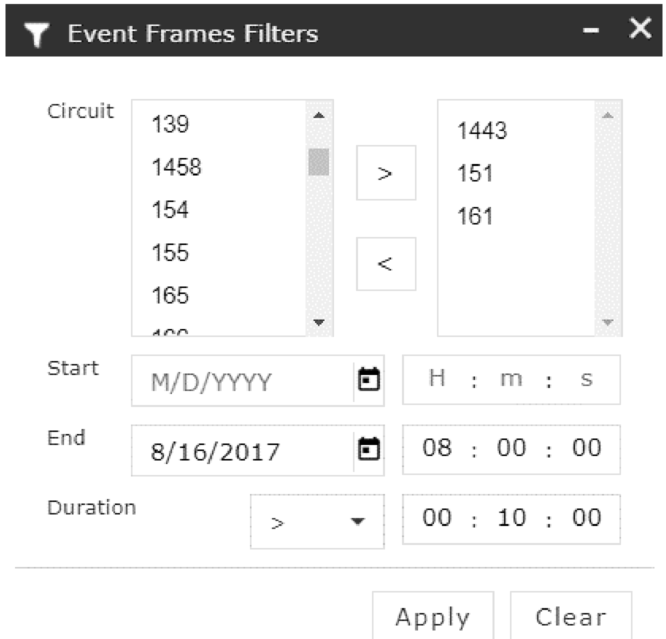


Figure 2-14. Custom Widget: Selecting Facilities of Interest

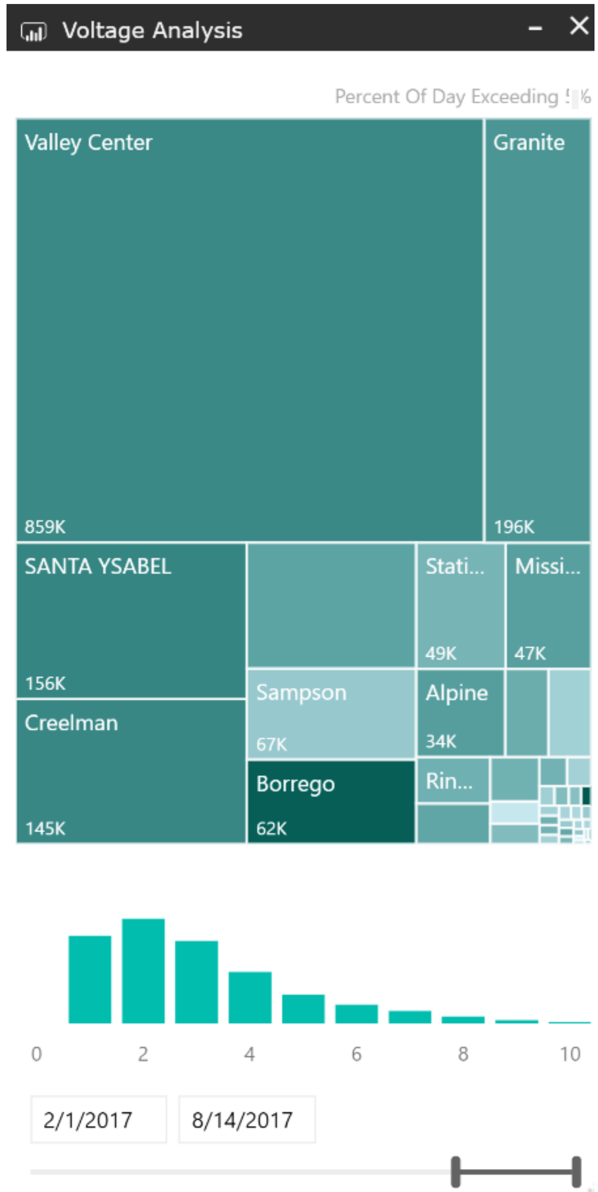


Figure 2-15. Power BI Display of Voltage Exceedance Events (tile size proportional to # of events)

The histogram at the bottom is the distribution of metering errors over the time horizon indicated in the timeline at the bottom of figure (from 2/1/2017 to 8/14/2017).

Selecting any of the boxes is akin to zooming in. For example, by "clicking" on Valley Center, the display will update to show the counts on meters within that station only, and the histogram will update to show exceedance by all meters in the Valley Center substation.

By a further zoom-in action, one can get to a breaker of interest shown in the left-hand side of Figure 2-16; details on the number of exceedances as shown by tile size on the right; the histogram of metered deviations below the tiles; and the timeline bar at the very bottom.

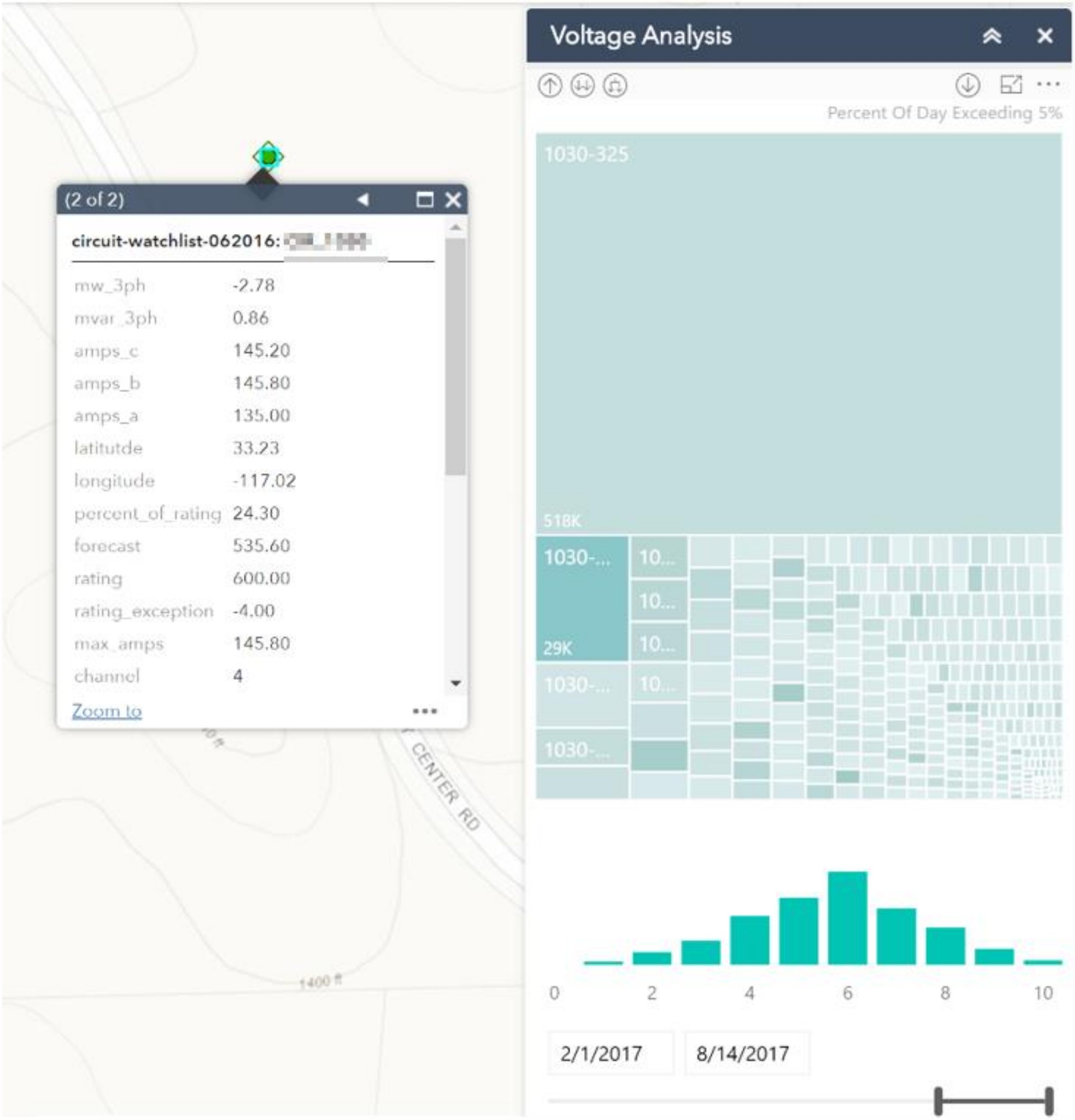


Figure 2-16. Breaker CIR_XX Events

Figure 2-17 shows an event loader configured to retrieve and display events for a given date, and an interval relative to that date specified by the values in the "From" and "To" fields. The asterisk (*) in the date field means current time; solid icon colors mean the event is still in effect at the end of the selected interval; hollow icons mean the event occurred and completed prior to the end of the specified interval.

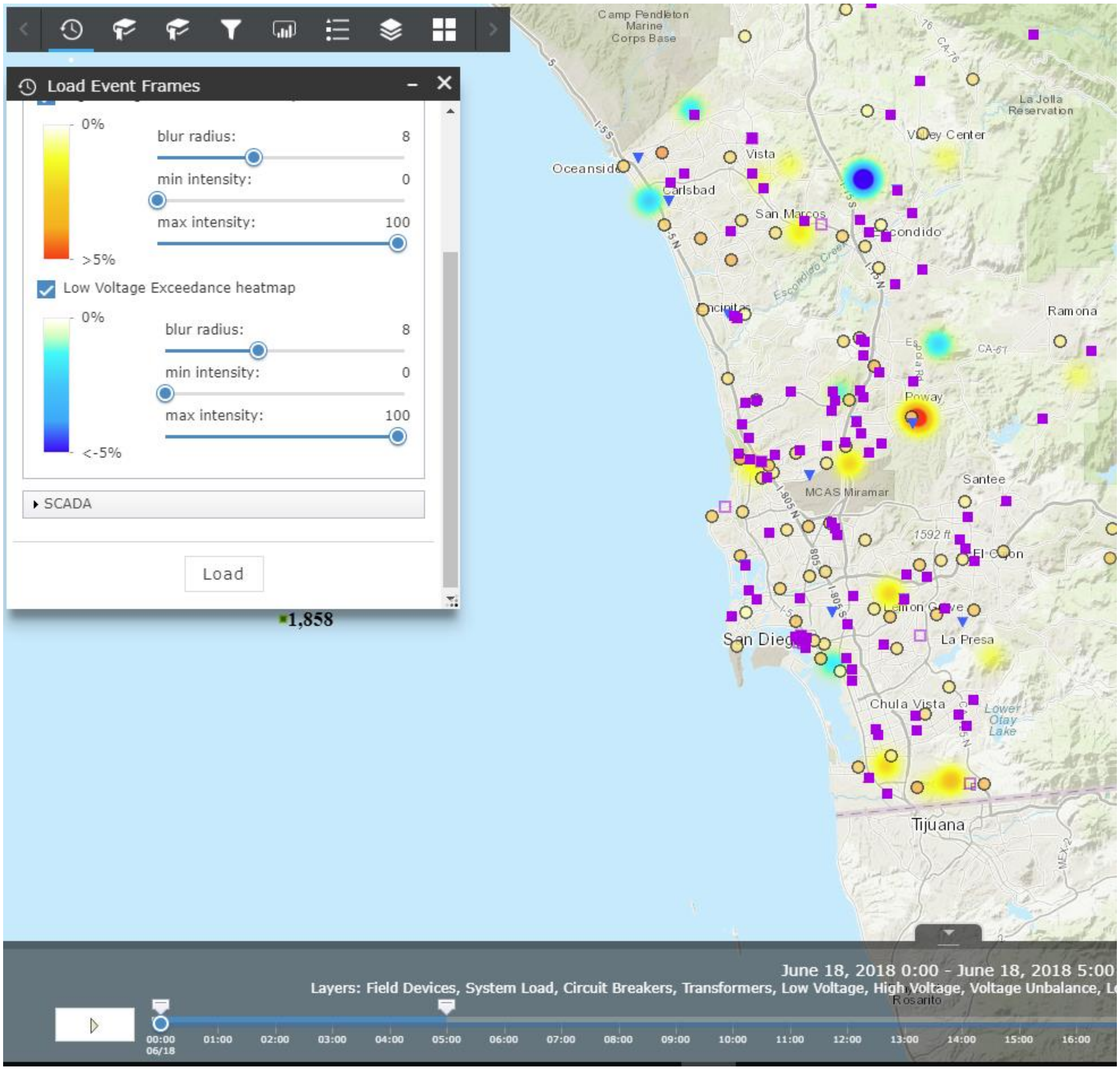


Figure 2-17. Custom Widget: Dynamic Heat Map of Voltage Exceedances over a Specified Time Interval

By "clicking" on an event, one gets additional details. For example, Figure 2-18 shows a, b, and c phase currents from SCADA at the event time. This illustrates a still ongoing event; hence, the square is filled with color, and End date/time is not filled in.

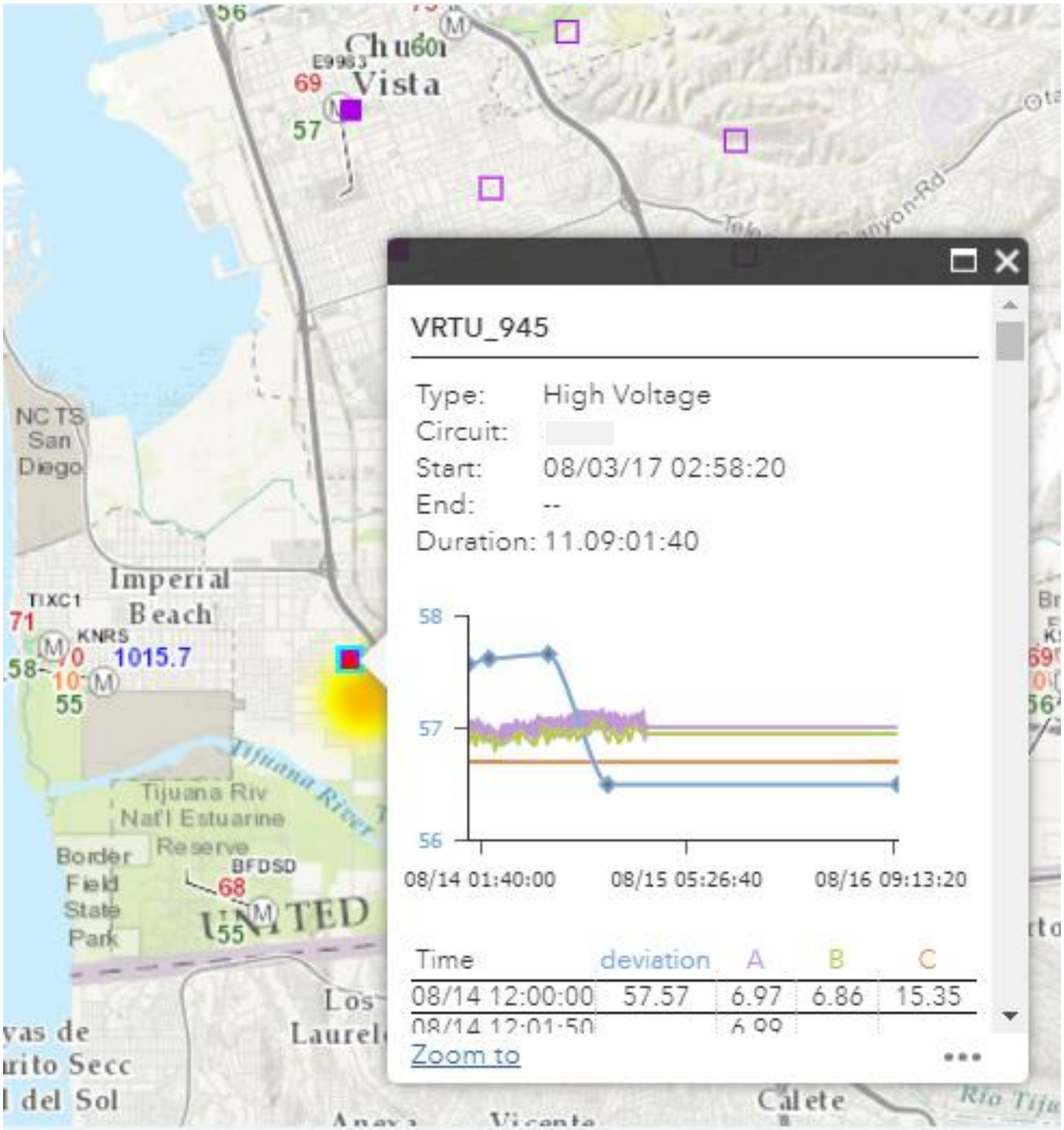


Figure 2-18. Event Detail: Voltage Chart

Figure 2-19 is a Power BI custom widget in conjunction with a geospatial display, showing tabular details of the events configured according to Figure 2-19. Due to the integration of Power BI with geospatial visualization, by selecting any element in the table, the corresponding element on the map is identified.

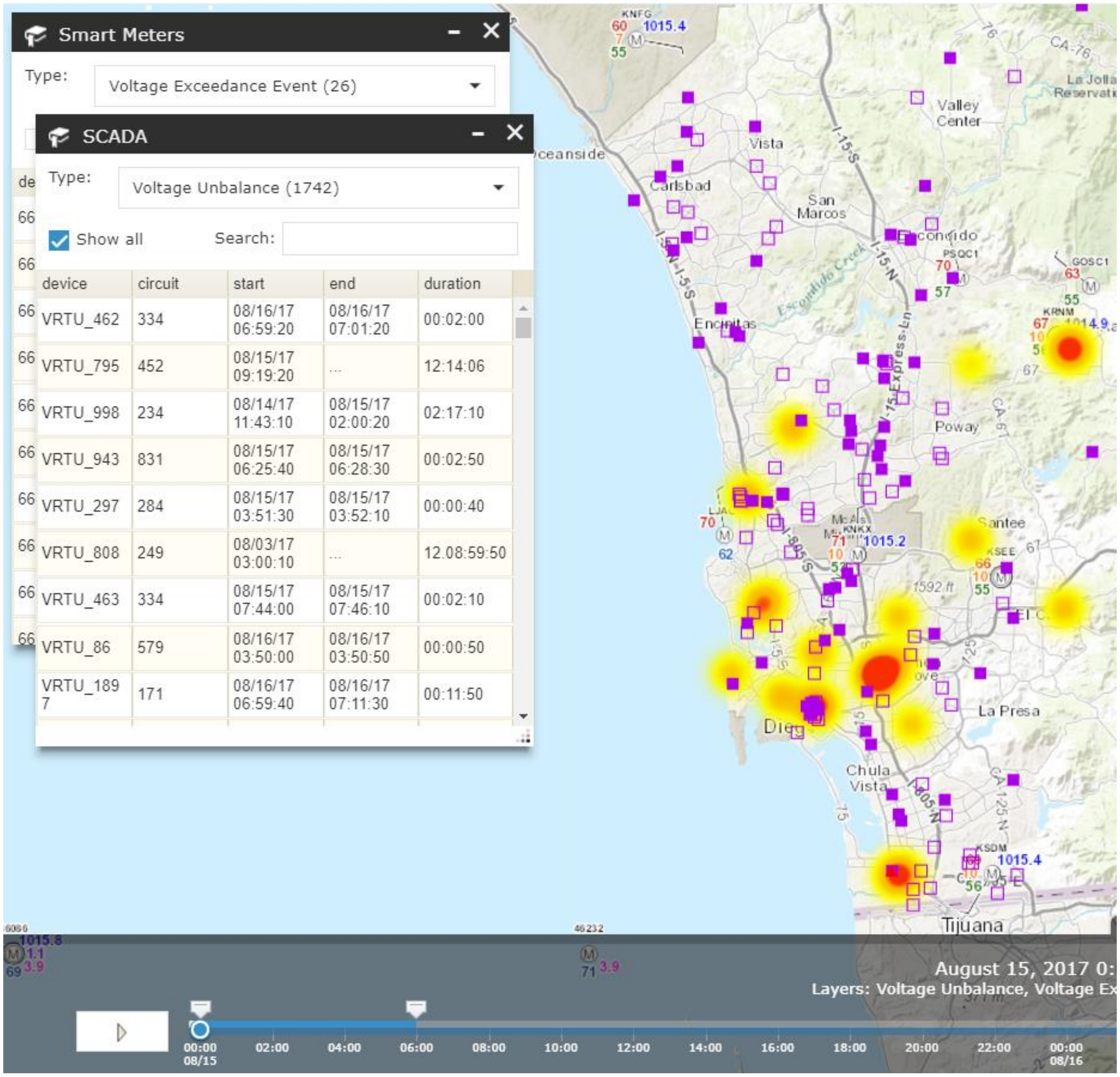


Figure 2-19. Custom Widget: Power BI Showing Voltage Exceedance

2.3.6 Observations, Challenges and Lessons Learned

Challenges and Resolutions

- Coming up with a solution to integrate Power BI and ArcGIS, with the solution that is configurable, so it can be reused. The task has been successfully solved with a custom program.
- Customizing Power BI widgets.
- Esri has a component for integrating Power BI with Esri maps, but that solution requires Power BI to also be on premises. In this case, Power BI was a cloud-based solution, and hence, SDG&E® needed to develop an alternative solution for integrating Power BI widgets within Esri maps.

- An early user's feedback indicated a need for customizable widgets, such as different symbols for the items that can be displayed on maps. As a result, the team developed a customizable widget for configuring symbols by the end user.
- Authenticating users with MS OAUTH (used by Power BI users) was a challenge: Power BI is a cloud-based application, the rest of the needed applications are on premises. The challenge was to implement a single sign-on in this hybrid environment due to a lack of templates (for accomplishing this task) and due to terse documentation. After a good deal of trial and error, the hurdle was overcome.
- Attempting to scale up the map event frames with PI AF would hinder resolution consistency. The decision to replace tasks handled by PI AF with SQL Server solved this issue. The SQL Server was already being used for Power BI, so it added consistency to the project.
- Currently gathering data from ~19,000 smart meters, scaled up from the previous 4,000. The project will be scaled to ~300,000 smart meters in Q3 2018, with new PI AF servers to be deployed to meet the demand for the influx of data.

<u>Recommendations</u>

- It is suggested to design custom widgets to be as generic as possible. In this project, that approach has proven to be very helpful, and it is expected that it will continue to be helpful in future projects.
- Applications should be designed to be customizable by end-users, which helps with usability, and ultimately, with adoption of the function.

2.4 Imagery Management (UC 4)

2.4.1 Background

An anticipated increase in the amount and variety of data from drones, imagery, video, and 3D sources necessitates a comprehensive data management strategy. The use case in module 1 explored and demonstrated technologies for integration and management of Light Detection And Ranging (LiDAR) data, imagery, and 2D data, with the goal to learn how to manage multidimensional data information efficiently. With successful building of an Image catalog to visually search through a wide variety of data, the use case further investigated, on how to use previously collected drone data with existing GIS data to improve data quality and analytic capabilities. And the possible uses for each type of data that is a part of Image Catalog are examined. Especially since LiDAR is more accurate spatial and temporal data, LiDAR data processing and deployment into web applications is studied in the below use case.

LiDAR data is considered appropriate mostly for surveying and engineering designs and used with surveying precision software like PLS CADD, but recent evolution of processing techniques in GIS software made it possible to visualize and analyze the LiDAR data in web applications, although not in surveying grade. This makes the LiDAR data readily available for a wide range of audience through GIS applications, either as a background for GIS data or as stand-alone application to develop predictive models for general overview.

2.4.2 Objective

The use case aims to demonstrate the ability to make the LiDAR data available through GIS applications, and compare against GIS data in 3D for visualization purposes. The use case also covers the research of prediction models for LiDAR data based analysis and possibility to construct these models into GIS as widgets to be used in a web application.

2.4.3 Users

- Vegetation Management
- Construction services
- Electric Transmission and Distribution Engineering

2.4.4 Solution Approach, Solution Components, and Work Flow

LiDAR data is available for multiple years and from multiple vendors, on a common NAS drive. The data is stitched into 1 dataset through Esri ArcPro tools. By converting to web manageable (web scene) format through ArcPro, the LiDAR data is hosted in ArcGIS portal web application for visualization in 3D. GIS tools can be modelled to manage this LiDAR data based on the algorithms mentioned below.

<u>Solution Components</u>

The following components are used for this use case,

1. ArcPro 2.0 – for processing LiDAR data and packaging it as a web scene
2. Web AppBuilder v2.7 – for building 3D web applications with LiDAR or 3D GIS data
3. ArcGIS Portal 10.6 is used for hosting the web scene as a service that can be consumed into the web application

<u>Work Flow</u>

The LiDAR data is cleaned for any outliers that occur during the collection of data. This data is considered as noise that can interfere with data analysis. To get accurate results the outliers are removed, and the misclassified data is corrected manually by selecting as many points as possible for recalibrating the data.

The recalibrated data is used for creation of the LiDAR dataset tiles. These datasets are published as scene service in ArcPro 2.0 to facilitate the consumption of point cloud data into web applications using Esri Web AppBuilder v2.7.

In this task, 3 sub use cases are researched for the LiDAR data based analytics for various departments. They are,

<u>Sub use case 1: Compare 3D and projected 2D data</u>

Overlay of projected 2D data such as poles with exaggerated heights to compare with LiDAR data for visual analysis of differences in heights. Such analysis will be more accurate with frequently updated LiDAR data.

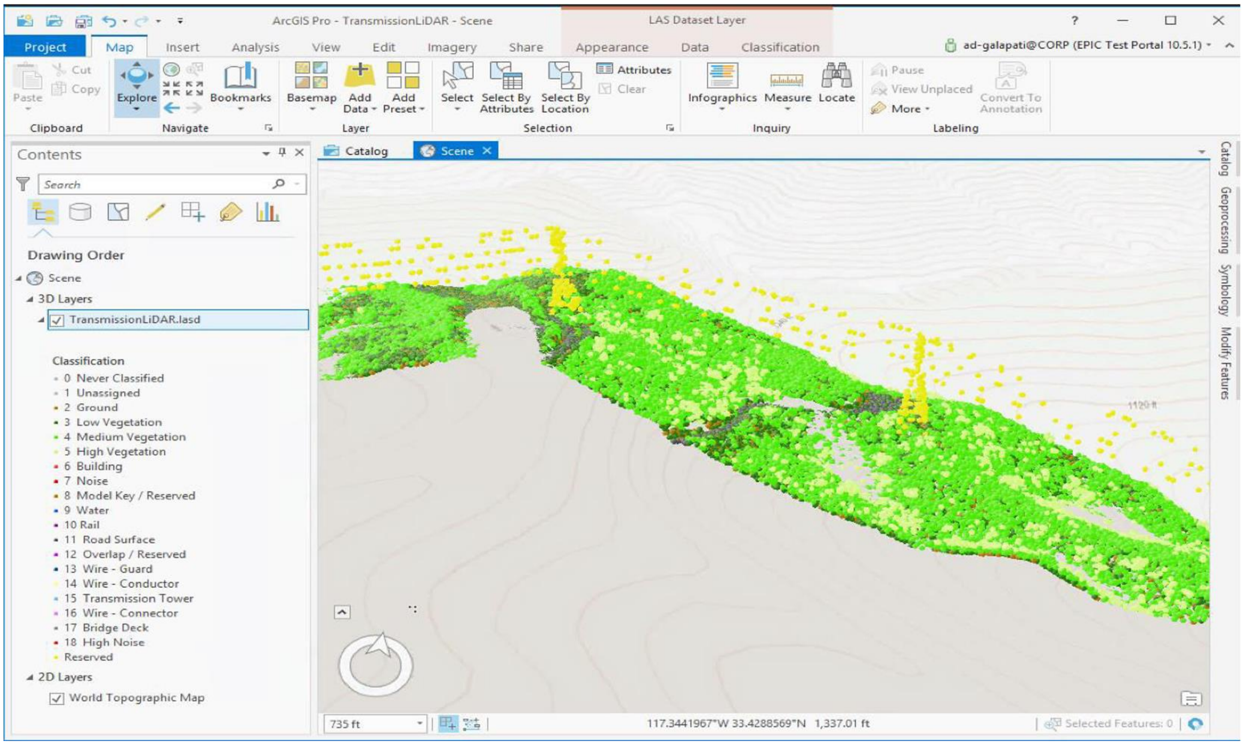


Figure 2-20. LiDAR data in ArcPro 2.0

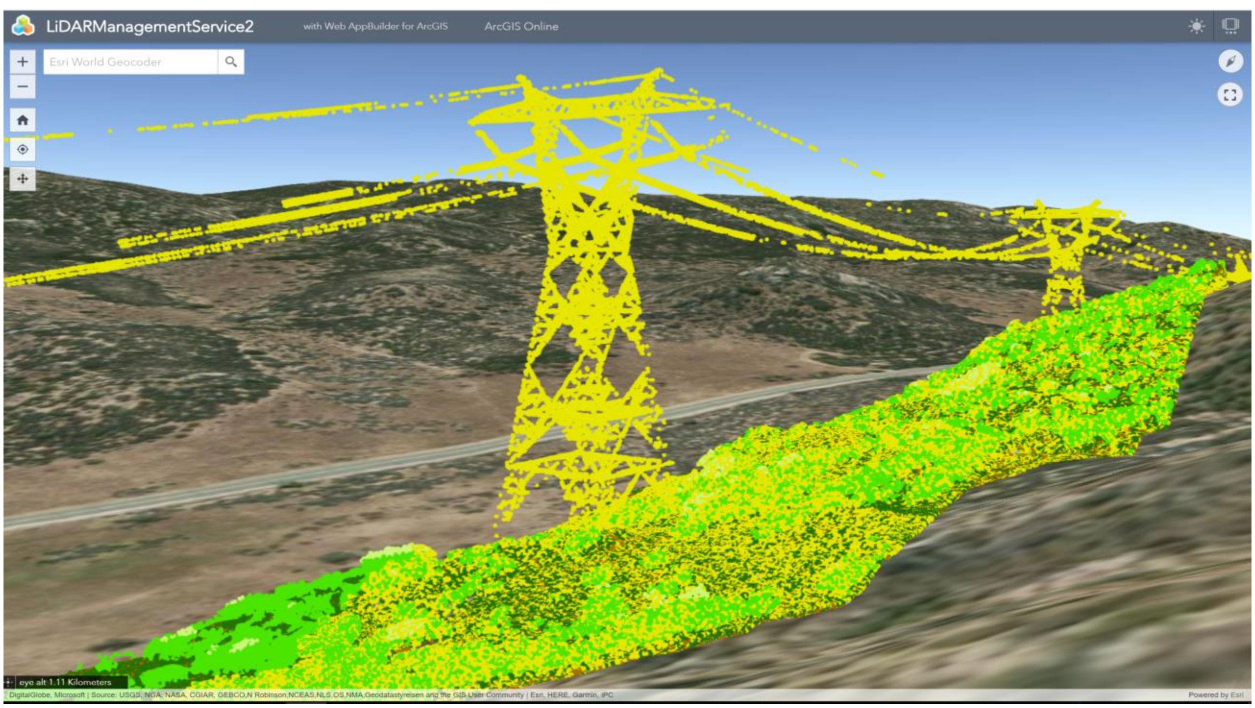


Figure 2-21. SDG&E LiDAR data in web application

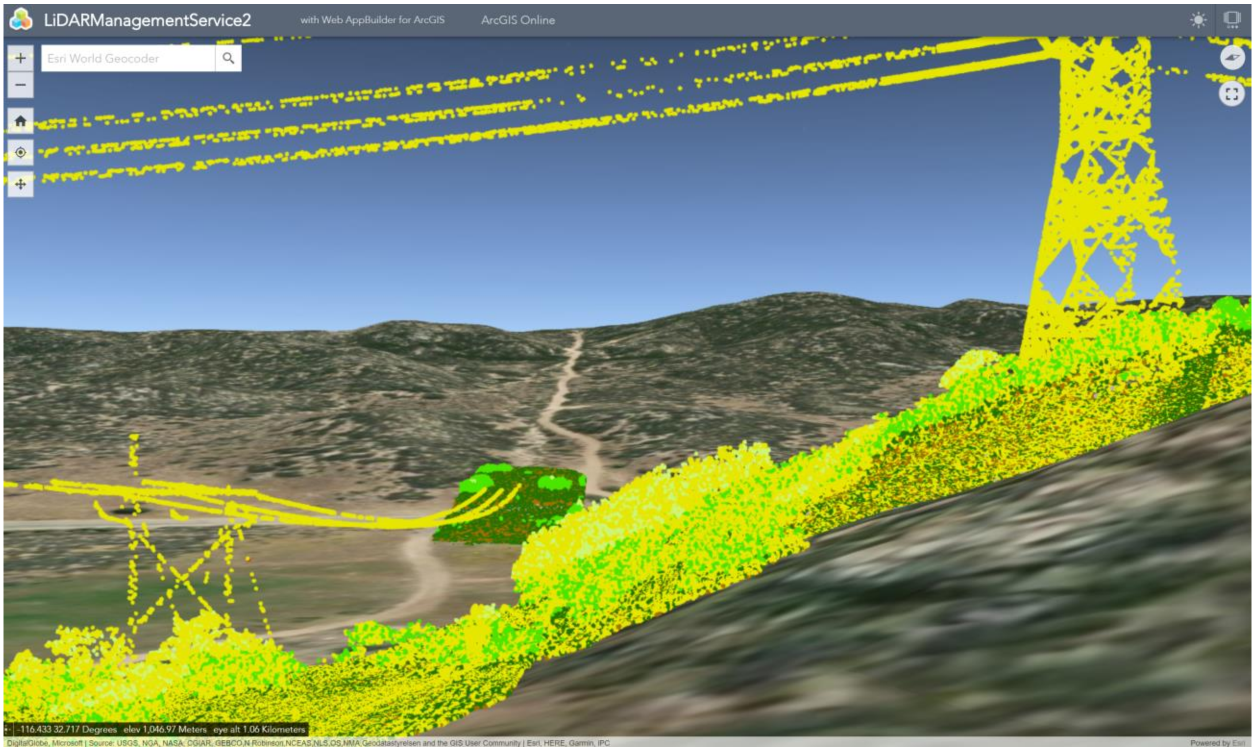


Figure 2-22. SDG&E® LiDAR data for both Transmission and Distribution data

The algorithms are researched according to the variables selected for the prediction models, to arrive at accurate variables for building the models. Although not demonstrated in this use case, the models will be built into widgets using geoprocessing service that can run the models.

Sub use case 2: Line sag/sway analysis

Line sag maximum under given wind and temperature

– Modelling of a custom widget to calculate deviation of line sag of a conductor will help model the maximum load conditions and to prevent any unnecessary load failures in wire conductors.

*Sag of Line (S)= Proportional constant(C) * Linear Expansion of material (ΔX) = C * {e * (T2 – T1) * X}*
*Height of the wire conductor above ground (Y_e) = (Y – S) *3.28 ft.*
*Sway in Line = Max sway of line for given wind conditions (S_W) per second= ($W_V * V$)/ (X * W) m*

- Parameter variables:
  - *Predicted temperature at the given location (In Degree Fahrenheit): T2*
  - *Standard wind pressure for wires: W_v^n N.m^{-2}*
- Assumptions: C*onsidering the linear expansion ∞ sag of conductor*
- *Variables for formulae:*
  - *Current temperature at the given pole location (in Degree Fahrenheit): T1*
  - *Co-efficient of linear thermal expansion: e*
  - *Surface of conductor exposed to the wind in m^2:A_V*
  - *Length of wire in meters: X (derived in GIS)*
  - *Height of wire in ideal conditions from ground in meters: Y (derived from LiDAR data)*

- *Weight of conductor: W kg* *(constant value)*
- *Radius of the wire conductor in meters: r* *(derived in GIS)*

- *Wind forces on conductor*[3]*(* W_V*)* = $W_v^n \cdot A_V$ N
- *Volume of conductor V = π * r*^{2} *** X m*^{3}

Sub use case 3: Vegetation encroachment for wire conductor

Vegetation encroachment can be calculated based on sites that may be in danger of interacting with the wire conductors and possible outage.

- Assumptions: the wind speed is standard, and the sway is only within the radius 'X' feet of the wire conductor. And the modelled sag is based off the maximum temperature
- Derived Δ of vegetation encroachment $(D) = W_T - \sum_{k=1}^{X} Z_V$
- *Modelled wire sag maximum Y from corresponding ground point (*W_T*) = W -* W_S *ft.*
- *Max. height of vegetation in a radius of 'X' feet =*Z_v *(derived from LiDAR data)*
- *Max. wire sag in Y direction =* W_S *ft.* *(derived from Line Sag algorithm)*
- *Current height of the wire conductor = W ft.* *(derived from LiDAR data)*
- *The max. height* Z_v *is iterated until all the levels of S1, S2, and S3 are calculated.*
- *S1, S2, S3 etc. specified vegetation encroachment levels and will be based on the 'D' value of the vegetation*

The resulting shapefile graphics is added as temporary graphics to the GIS map. The graphics are symbolized by severity.

2.4.5 Results

The LiDAR data based web application can serve for visualization of data in 3D and shared across the departments based on user access. Further, by creating custom widgets to analyze the data these 3D applications can be used for various purposes like line sag analysis based on predicted weather scenarios, vegetation encroachment analysis to make decisions on vegetation trimming.

2.4.6 Observations, Challenges, and Lessons Learned

Challenges and Lessons Learned

The key approach to establish the algorithms and develop the tools is a challenge. Although various factors will affect the real-world scenarios, these prediction models will try to close the gap between ideal and real-world scenarios.

These predictive models combined with regular data collection, will assist field engineers and decision makers to get a general idea of the field conditions in extreme weather situations.

The initial phase of testing the LiDAR data usage in GIS is successful. The testing of the prediction models will require considerable amount of time and effort and the variables to create correct predictive

[3] ***Wind Load of Overhead Electrical Lines Exceeding AC 1 kV** By Stanislav Ilenin, Ladislav Varga*

models should be tailored to the utilities based on data available and previous experiences of the utilities.

Future considerations

Esri is developing Alpha version of LiDAR analytic tools that will be integrated in future version of ArcPro software, for a more flexible way of building models based on LiDAR data. This could leverage GIS software like Esri to handle LiDAR analysis with more efficiency.

The 3 tools that are currently in alpha version are,

1. Create initial 3D catenary
2. Line adjustments
3. Line sag correction

1. Create initial 3D catenary: This tool takes as input attachment points and creates 3D catenaries between the points using default sag for each line. This tool is handy when the user only has attachment points and nothing else. It will create catenary lines, as illustrated in **Error! Reference source not found.**.

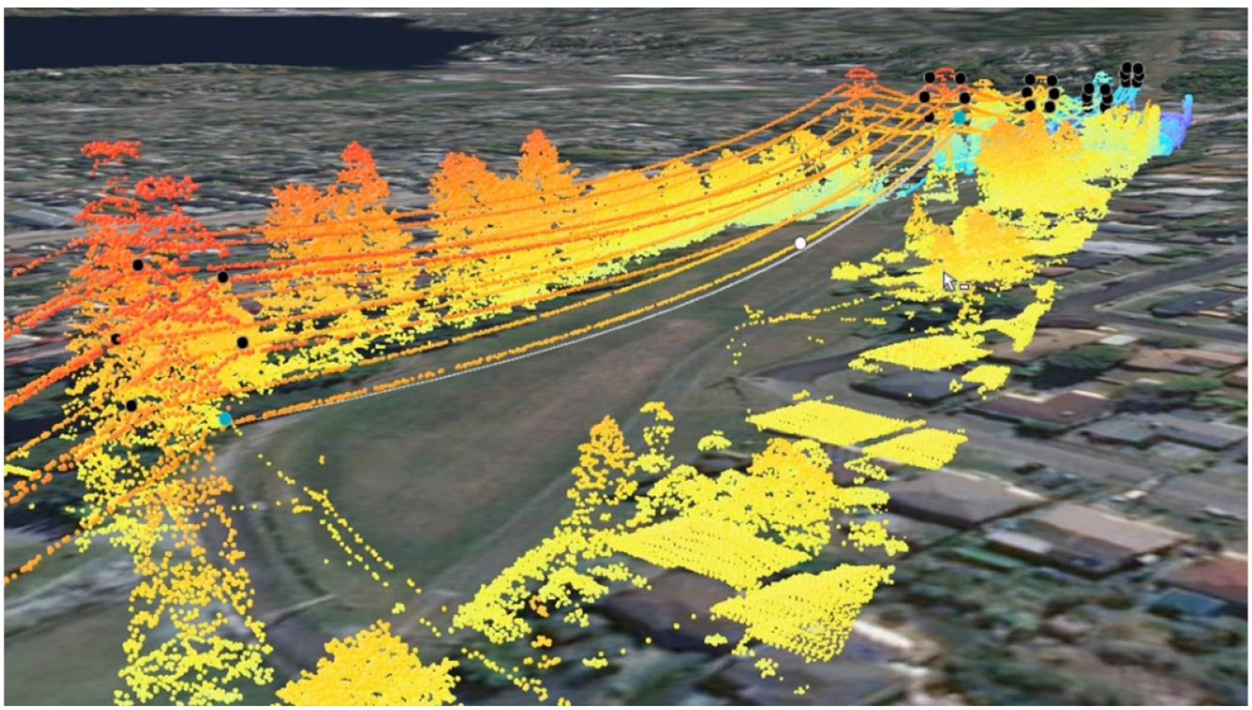


Figure 2-23. Initial catenary

2. Line adjustments: Line adjustments can be made that will allow the user to manually adjust 1 line per span to the LiDAR data (if they have that), giving a sag adjustment factor, which then can be used to improve the sag of the other lines in the span. **Error! Reference source not found.** represents the adjustment of lines as a result of the processing.

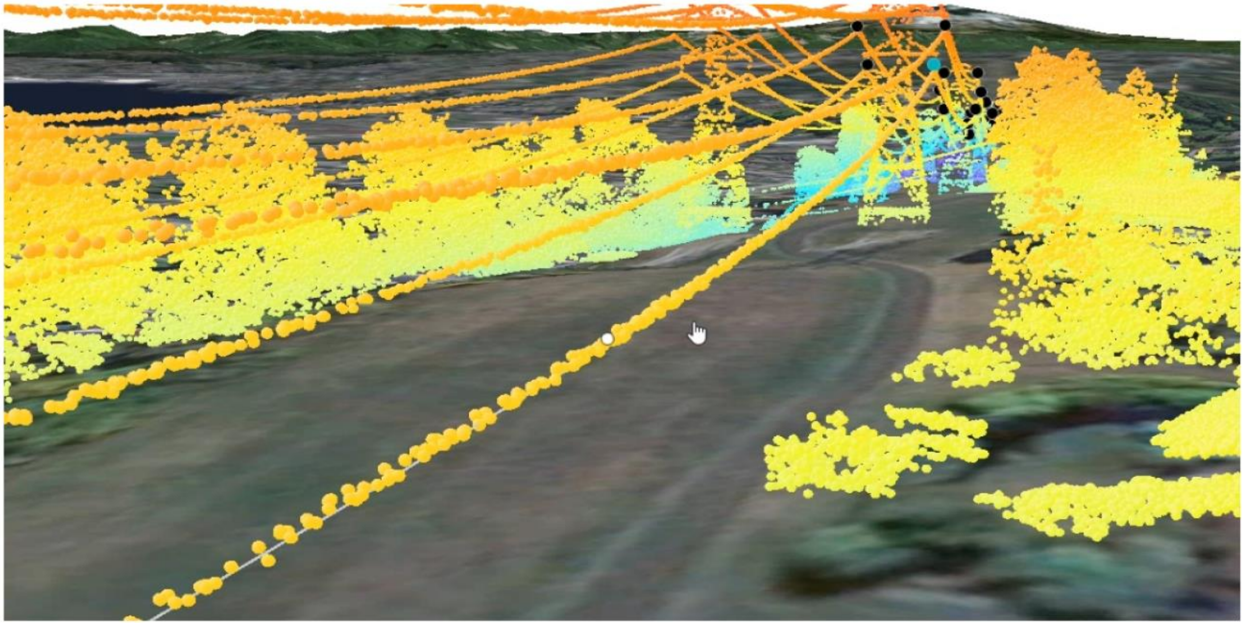


Figure 2-24. Line adjustment

3. Line sag correction: This tool will allow the user to enter wire information, tension information, for automatic calculation of correct sag by calculating line sway. The modelling of the tool by creating a mesh with the sway as radius to find LiDAR points intersecting, is demonstrated below in Figure 2-25

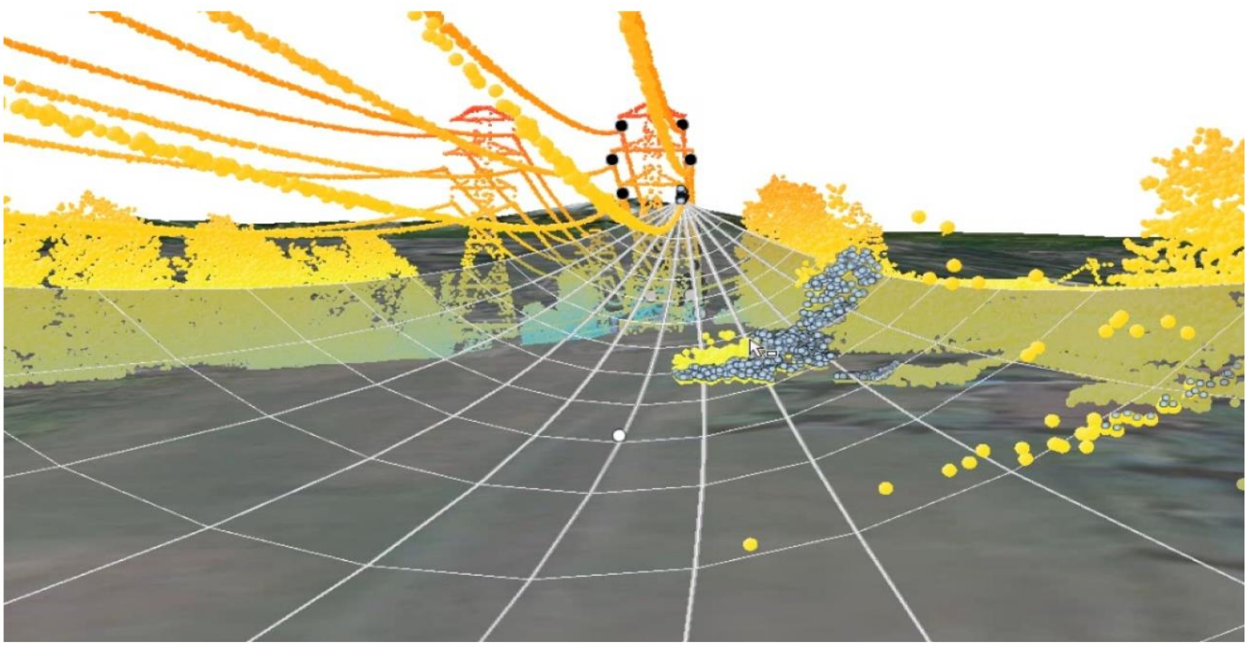


Figure 2-25. Modeling line sway and calculation of LiDAR points that might interfere.

The diagrams Figure 2-23 through Figure 2-25 represent the results of the tools using synthetic data and the figures do not reflect SDG&E data. The development of these tools will enhance the quality of prediction models in GIS. The level of detail that can be achieved and the reliability of the prediction models demonstrated in the use case will increase. As these tools reduce the burden of programming pre-modelling data preparation of the LiDAR data.

Recommendations

- The initial effort to stitch the data and clean the data for any outliers or recalibrate misclassified data, is considerable. More automated processes will help reduce the time required for this initial setup.
- The algorithms need to be fine-tuned by testing against real time data.

2.5 GIS Visualization Infrastructure Modernization (UC 5)

2.5.1 Background

At San Diego Gas and Electric (SDG&E®), the GIS technologies currently implemented for visualizing assets and electrical connectivity as 2D circuit maps and schematics are being considered for upgrade to latest technologies to explore the new functionalities.

Over the last few years, the GIS-specific technologies, and broader technologies with a potential to impact GIS visualization, have seen significant transformation. The most notable of these changes are:

- More expressive utility network modeling capabilities that allow for a more comprehensive details capture, as well as more powerful and functional engines that process these models
- Hardware virtualization
- GPU processing
- Software component interfaces via Web Service architecture
- Web browser functionality for viewing, editing, and tracing electric networks
- 3D maps that can support augmented and mixed reality consumption
- Real-time data from drones, Internet of Things (IoT), and smart devices
- Open source technologies
- Machine learning

It is inevitable that at least some of these advancements will find a way to improve GIS visualization capabilities in the industry at large and at SDG&E® in particular. With a view toward inevitability of improvements in the SDG&E® GIS capabilities through accommodations of more advanced GIS and GIS-related technologies, SDG&E® envisions a need to research and identify those modernizations in the industry (including hardware, software, data model, connectivity, and databases) that can help to better support SDG&E® visualization of asset maps and schematic diagrams, both in the office and in the field. The specific modernizations of interest are:

- **Hardware:** Modernize CPU with GPU processor
- **Virtualization:** Modernize Citrix with VM Ware
- **Software:** Modernize 32-bit ArcMap with 64-bit ArcGIS Pro
- **Architecture**: Modernize direct database transactions with services-based transactions

- **Data Model:** Modernize the current Electric data model with Utility Network data model
- **Data Content:** Modernize asset content by reducing abstraction from field and as-built conditions
- **Connectivity:** Modernize Geometric Network with Utility Network
- **Database:** Modernize Oracle
- **Apps:** Modernize front-end Web technology with Node.JS-based technology

These examinations will require significant effort, spread over time. Examinations within this use case constitute a beginning of this effort and have as its objective a subset of the required activities as listed in the next section.

2.5.2 Objective

The objective of Use Case 5 was to conduct an initial investigation of hardware and GPU virtualization, the digital model for electric network/connectivity in GIS, as well as options to modernize the front-end Web technology.

2.5.3 Users

- GBS – GIS Business Solutions
- T&D Engineering
- Electric T&D Construction

2.5.4 Solution Components, and Approach

2.5.4.1 Solution Components

- GPU Hardware Appliance
- GIS Desktop Software (ArcGIS Pro)
  - Avineon Model Manger Add-In for ArcGIS pro
- Avineon GN2UN Tools
- GIS Server and Portal Software (ArcGIS Enterprise)
- ArcGIS Web AppBuilder Software widgets
- Web AppBuilder widgets for ArcGIS
  - Net Explorer by Avineon

2.5.4.2 Solution Approach

Hardware and Virtualization

As part of the EPIC technology demonstration, SDG&E® through Avineon used ArcGIS Pro and Esri Utility Network (UN) together with a Hypervisor hardware/software appliance equipped with NVIDIA GRID technology. In other words, a virtual desktop and virtual application approach was used to provision the new GIS and network utility model.

The Hypervisor is a powerful server that is used for running Virtual Machines (VM) to deliver the ArcGIS Pro application to the end users. At SDG&E®, desktop GIS users use the VMware ESXi 6.0. At the Hypervisor Operating System level, the VMware ESXi is an operating system running its own kernel that manages the desktop VM. A VMware product known as vSphere allows for an administrator to provision and manage the VM. In vSphere, administrators can configure and allocate vGPU (virtual Graphics Processing Unit) for the VM pool.

For the EPIC demonstration project, SDG&E® acquired two Tesla M60s to make up the NVIDIA GRID GPU portion of the Hypervisor appliance, allowing for a total of 16 GB of DDR5 VRAM (Video RAM) (8 GB's per GPU). NVIDIA's GRID vGPU Manager allows administrators to create 1-GB through vPC license, 2-GB, 4-GB, or 8-GB through vWS license, vGPU's for the Virtual Desktop pools. The respective profile details for vPC and vWS licenses are outlined in **Error! Reference source not found.**, Figure 2-27

For load testing, the following ratios are estimated: 1 GB = 16 Virtual Machines, 2 GB = 8 Virtual Machines, 4 GB = 4 Virtual Machines and 8 GB = 2 Virtual Machines. Using the various profiles, SDG&E® plans to obtain performance metrics to help understand user density optimizations. For this EPIC demonstration, the configuration applies to the VMware products ESXi, vSphere, and Horizon View.

At a high level, the diagram (Figure 2-28) from NVIDIA illustrates how it works.

GRID Virtual GPU	Intended Use Case	Frame Buffer (Mbytes)	Virtual Display Heads	Maximum Resolution per Display Head	Maximum vGPUs per GPU	Maximum vGPUs per Board
M60-1Q	Power User, Designer	1024	2	4096×2160	8	16
M60-0Q	Power User, Designer	512	2	2560×1600	16	32

Figure 2-26. vPC profile details

GRID Virtual GPU	Intended Use Case	Frame Buffer (Mbytes)	Virtual Display Heads	Maximum Resolution per Display Head	Maximum vGPUs per GPU	Maximum vGPUs per Board
M60-8Q	Designer	8192	4	4096×2160	1	2
M60-4Q	Designer	4096	4	4096×2160	2	4
M60-2Q	Designer	2048	4	4096×2160	4	8

Figure 2-27. vWS profile details

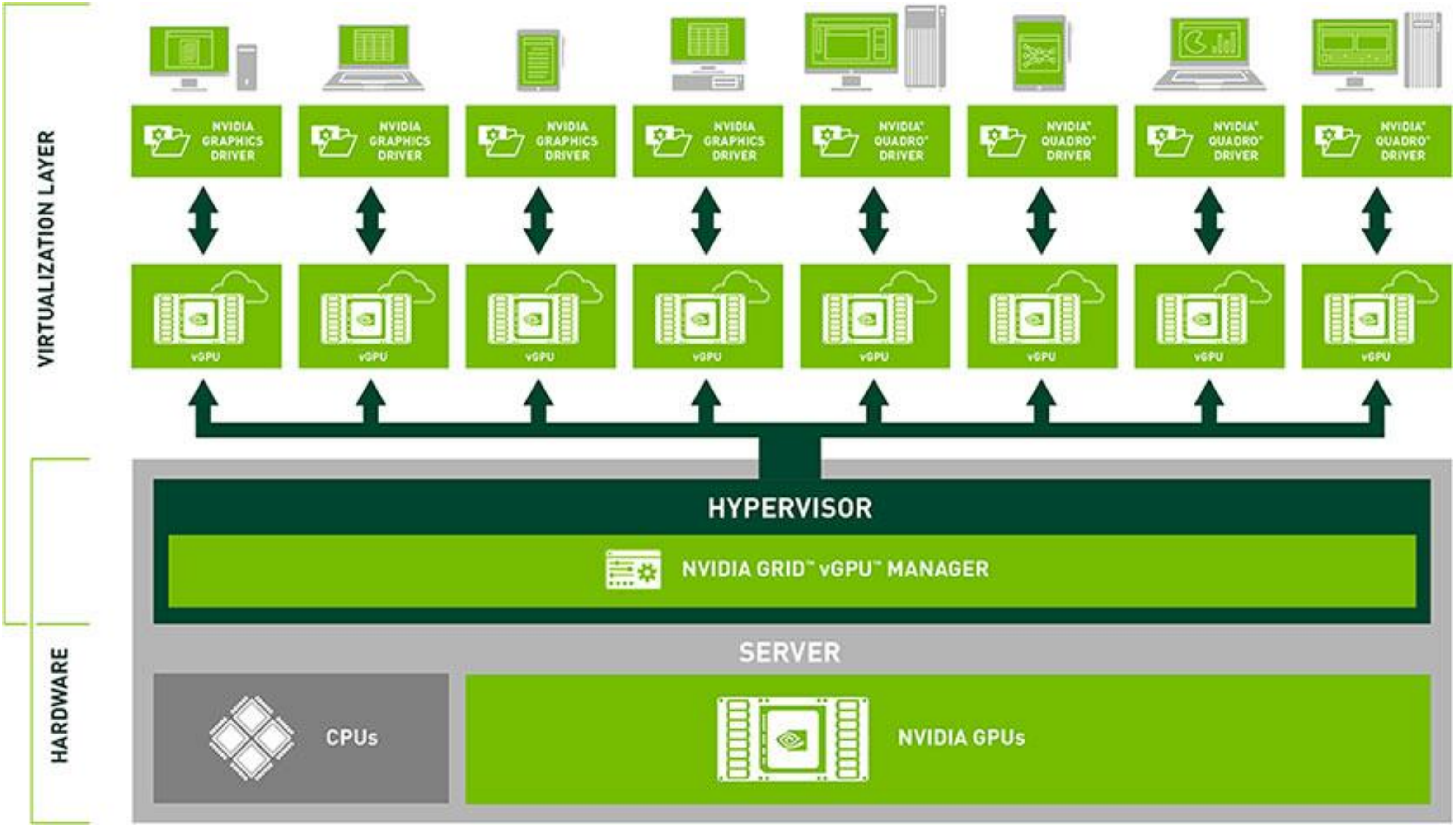


Figure 2-28. Virtualization of GPUs

VDI versus Terminal Services Discussion

As noted, the GPU server Hypervisor servers can also be supported on the VMware or the comparable Citrix environments (XenServer and XenDesktop). Currently at SDG&E®, the electric GIS desktop is deployed using a Citrix XenApp (terminal services) approach. From the business user's perspective, they are accustomed to using several applications at the same time. For productivity, their preference is to access multiple applications using the same virtual desktop window. To satisfy this need, using the XenDesktop approach would require the various applications that would require a different Virtual Desktop images. Additionally, they would need different Virtual Desktop pool deployments to support the different application licensing. With XenApp, it is not possible to simply add all applications into one image to meet each of the user needs.

From an IT perspective, the preference is also to deploy a desktop using the Citrix XenApp application virtualization rather than XenDesktop (VDI). The XenApp allows the teams to rapidly deploy GIS updates. From the Citrix administration standpoint, dealing with the client image management and non-GIS applications users' need is of less of concern.

For the EPIC technology demonstration, the focus was on VDI deployment. Via discussions with the technology vendors, it was found that using XenApp paired with ArcPro resulted in reduced application performance. This was not a Citrix limitation or an issue with ArcGIS Pro but rather the Server Operating System (Microsoft Windows). In a XenApp scenario, one typically assigns a vGPU to a Virtual Server. When a user launches an instance of ArcGIS Pro via XenApp, a session is created on the Virtual Server with no resource allocation guarantee for users. Essentially, what ends up happening is, as users spin up sessions on the Virtual Server via XenApp, the Frame Buffer (a portion of the VRAM for storing bitmaps which make up screen display to the user) runs out of memory. After about four users, XenApp Server reaches a state of reduced performance.

This will be something that SDG&E® needs to consider in the future because the current deployment relies on XenApp. With the expected production deployment of ArcPro and Esri Utility Network several years away, it is hoped that there will be sufficient time to design a strategy to deliver Virtual Desktops to GIS users that present them with a good experience.

2.5.4.3 Software, Architecture and Apps

Desktop Software and Architecture

The ArcGIS 64-bit ArcGIS Pro desktop software to modernize the current 32-bit ArcMap along with services-based transactions were investigated for analyzing, viewing and editing the digital model. This investigation was performed using one distribution circuit (520) and two transmission lines in SDG&E's service territory. It included the configuration and testing of following out-of-the box capabilities in ArcGIS Pro, as illustrated in the **Error! Reference source not found.**

1. Network Topology
2. Associations (Connectivity, Structural Attachment and Containment)
3. Advanced Network Tracing
4. Network Diagrams
5. Subnetwork Management

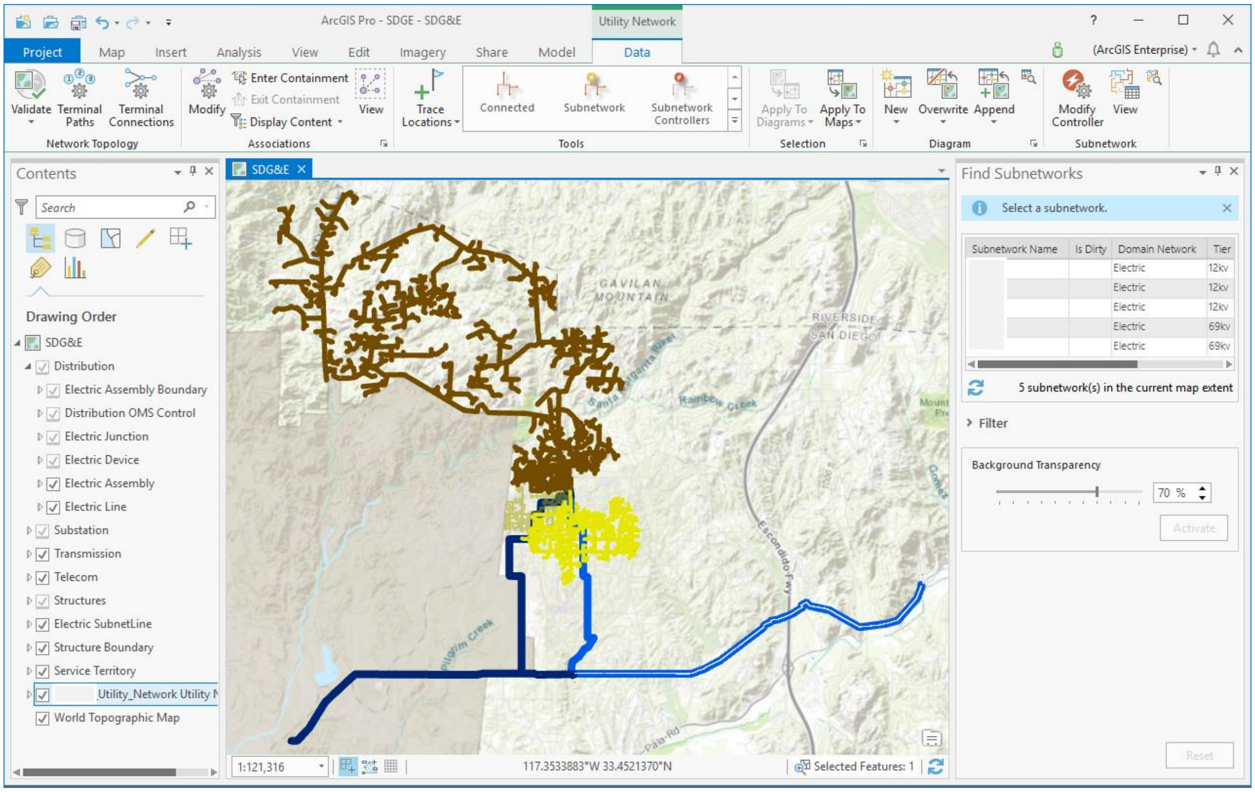


Figure 2-29. Out-of-the box capabilities of ArcGIS Pro for Utility Network model

The out-of-the box ArcGIS Pro tools for subnetwork controllers, terminal connectivity, network connectivity, non-graphical associations, and containments were tested across the distribution circuit and transmission lines as illustrated in **Error! Reference source not found.**

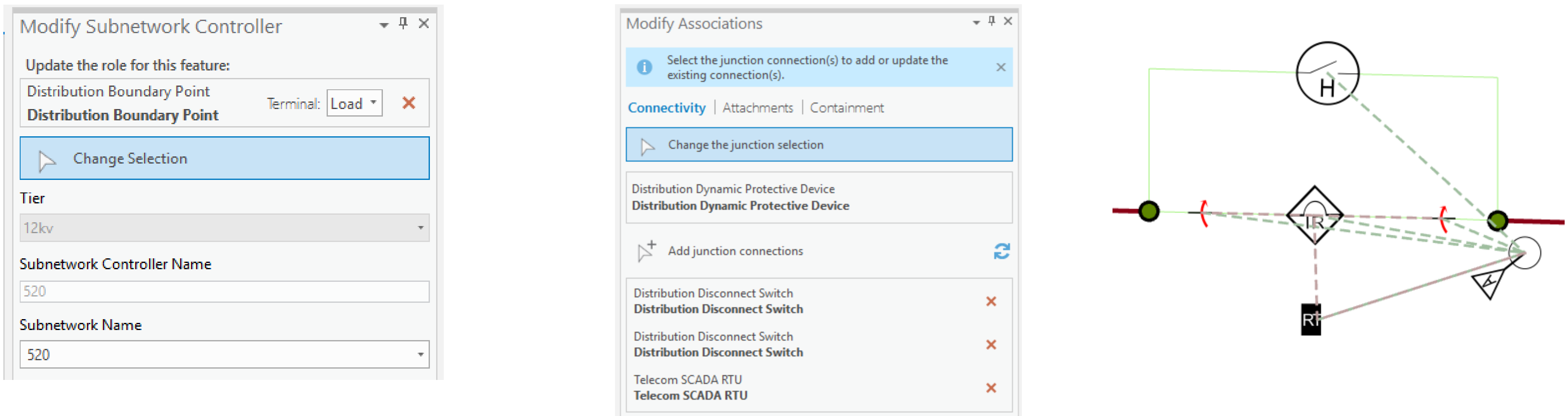


Figure 2-30. Out-of-the box ArcGIS Pro tools

The services-based transactions for visualizing and editing assets data and connectivity within the digital model using ArcGIS Pro were examined and contrasted to the current ArcMap database connected transactions in Figure 2-31.

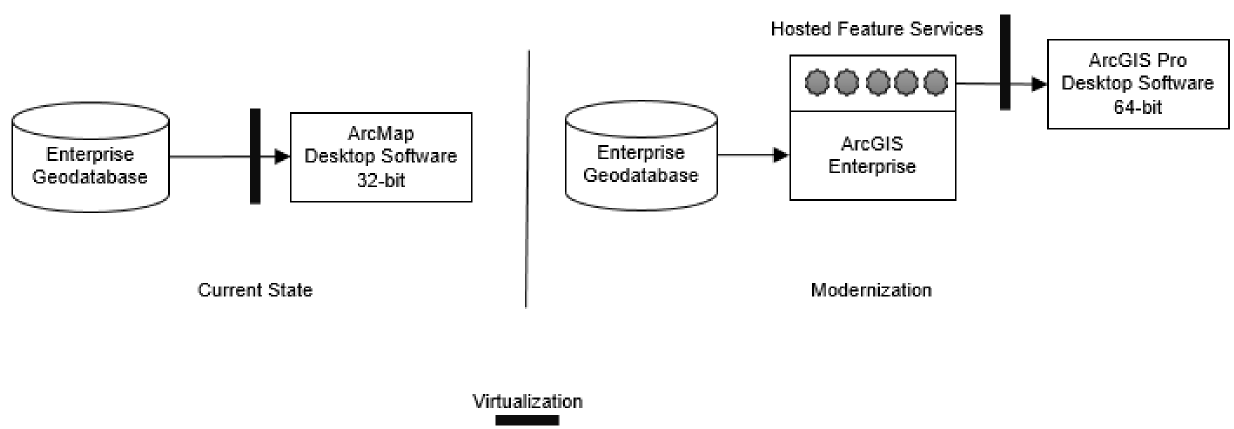


Figure 2-31. Architecture of database editing within Utility Network model

The resulting data model is examined for the individual layer properties to understand the basic differences in the previous data model to utility network data model in the Figure 2-32.

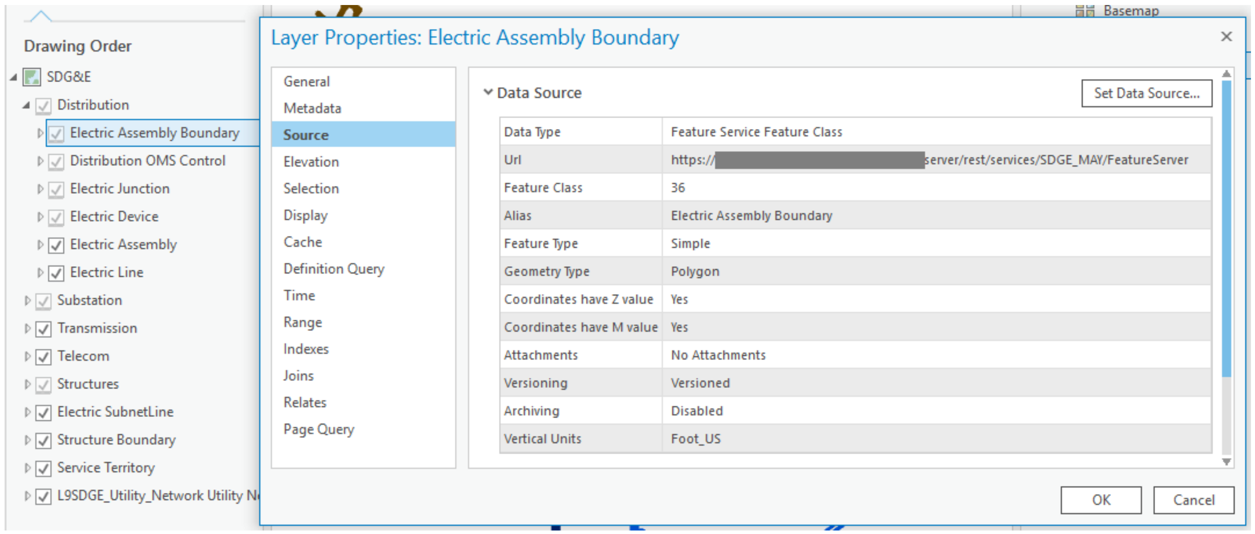


Figure 2-32. Layer properties

The investigation included the effort to examine the generation of Summary Operating Map (SOM) diagram for a circuit as illustrated in **Error! Reference source not found.**. A preliminary analysis for modernizing the current SDG&E® custom schematic diagrams capabilities with the modern network diagrams capabilities was conducted.

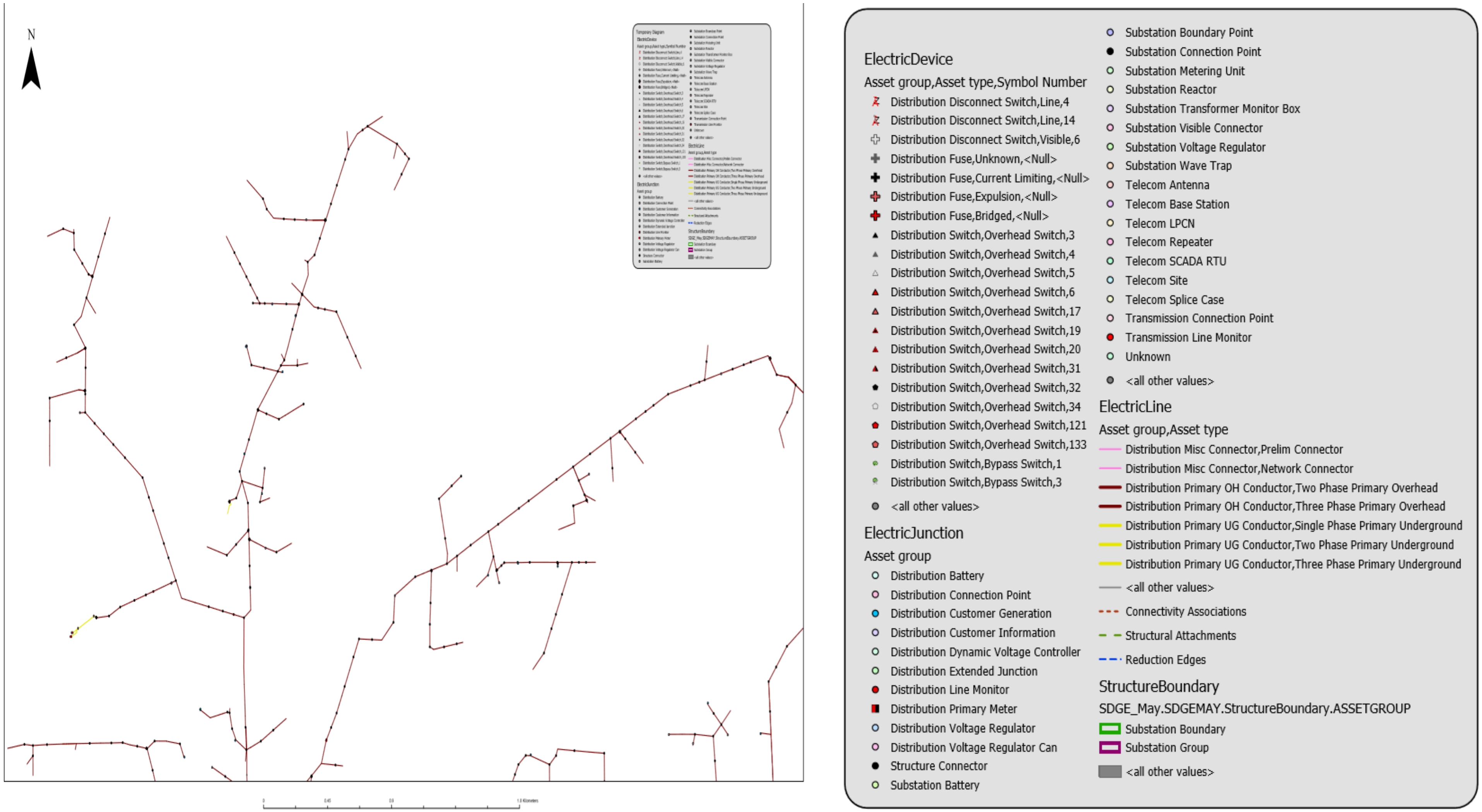


Figure 2-33. SOM diagram and legend of the circuit

Front End Web Technology

ArcGIS Web AppBuilder is used to develop the web application and was used to test the visualization and analysis of electric network from web browser. The Javascript widgets (Node.JS) were utilized in place of legacy Microsoft Silverlight technology within the web application. The 2D ArcGIS widget library served as the primary source for examining the data visualization and analysis functionality for front end web application. In addition, the NetExplorer widget from Avineon demonstrated an opportunity to modernize Silverlight technology.

NetExplorer

NetExplorer widget is used in this use case to trace, visualize, and report on electric/gas/water networks within GIS web application. The widget supports electric tracing in geometric network connectivity (current state at SDG&E®) as well as the modernized state (utility network connectivity).

Similar to the tracing functionality available in desktop GIS, this web widget provides the following functionality for users to perform:

a) One-Click traces
b) Specify starting points and stopping points (optional) and run traces as demonstrated in Figure 2-35

The key capabilities of this widget are:

1. Select Trace to Run
2. Key In Parameters
3. Select Stopping Points (optional)
4. Run the Trace
5. View Summary of Trace Results
6. Summarize Trace Results By Fields of Interest
7. Interact with Trace Results
8. Save Trace Inputs for Reuse
9. Select Network to Trace
10. Specify Trace Task
11. Specify Starting Points for the Trace
12. Specify Trace Options

When a trace is run the results are displayed along with related features if the ‘Show Related’ on Output tab shows related information for the selection. In the ‘Details’ tab, there is an option to display related records by features. The results can be saved with a name and shared with other users.

The configuration of this widget is demonstrated in Figure 2-34

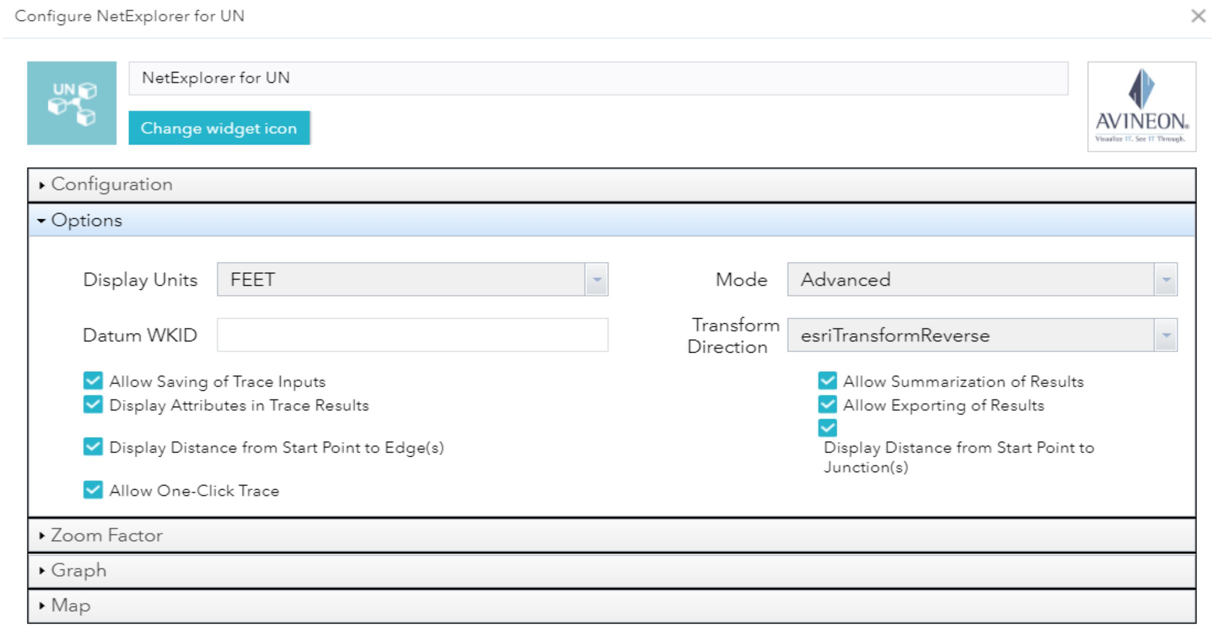


Figure 2-34. Configuration of the NetExplorer widget

The trace results displayed on the map are summarized by each GIS layer as demonstrated in Figure 2-36. The trace results are also available for deeper interrogation and analysis. The widget have ability to publish re-usable trace libraries for end users such as Network Off an Asset, Protective and Isolation Devices, etc.

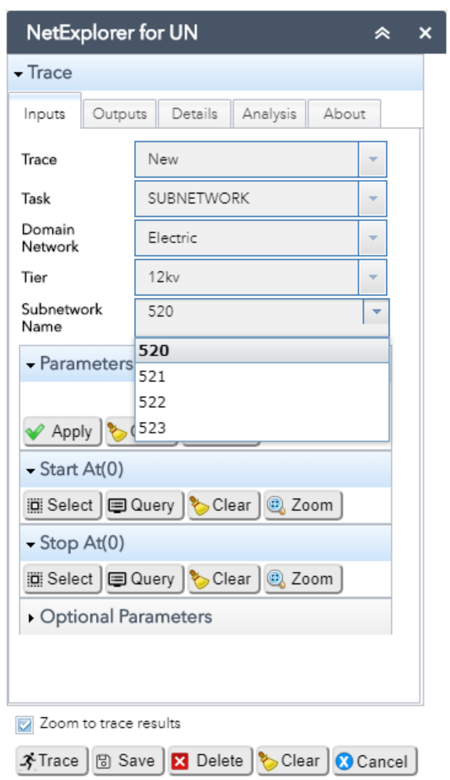


Figure 2-35. Input parameters for NetExplorer widget for utility network

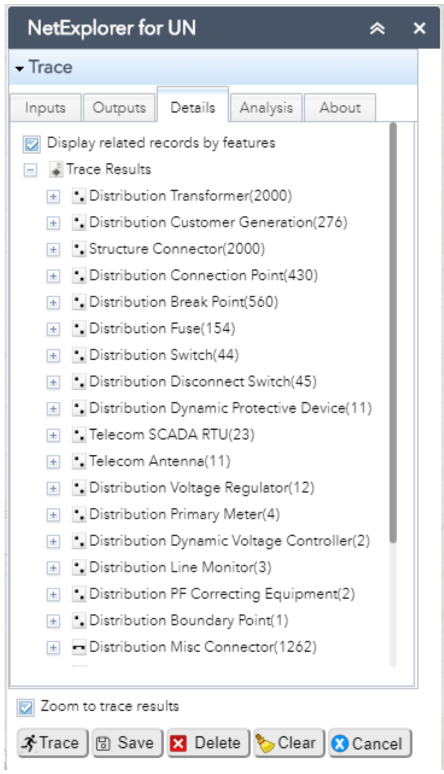


Figure 2-36. Displaying results for the tracing utility network

Figure 2-37 illustrates the use of NetExplorer widget for subnetwork and downstream tracing, the ability to highlight the results in a map view and interact with them through a tree view.

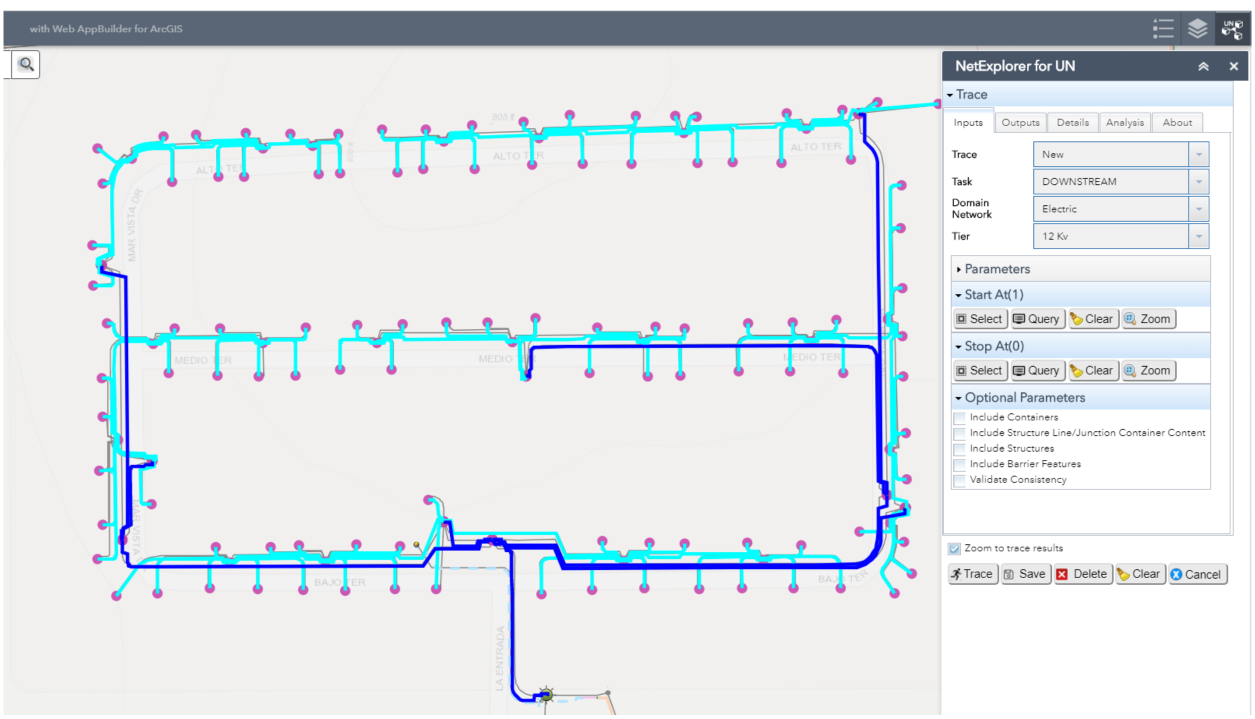


Figure 2-37. Displaying trace results on map

The results of asset connectivity are easy to visualize, along with interface to interact with trace results in

a) Map View
b) Tree View
c) Graph View
d) Summary Tables

The widget provides functionality to visualize network connectivity as graphs illustrated in Figure 2-38. This capability enables condensed view of network connectivity spread across a large geographic area.

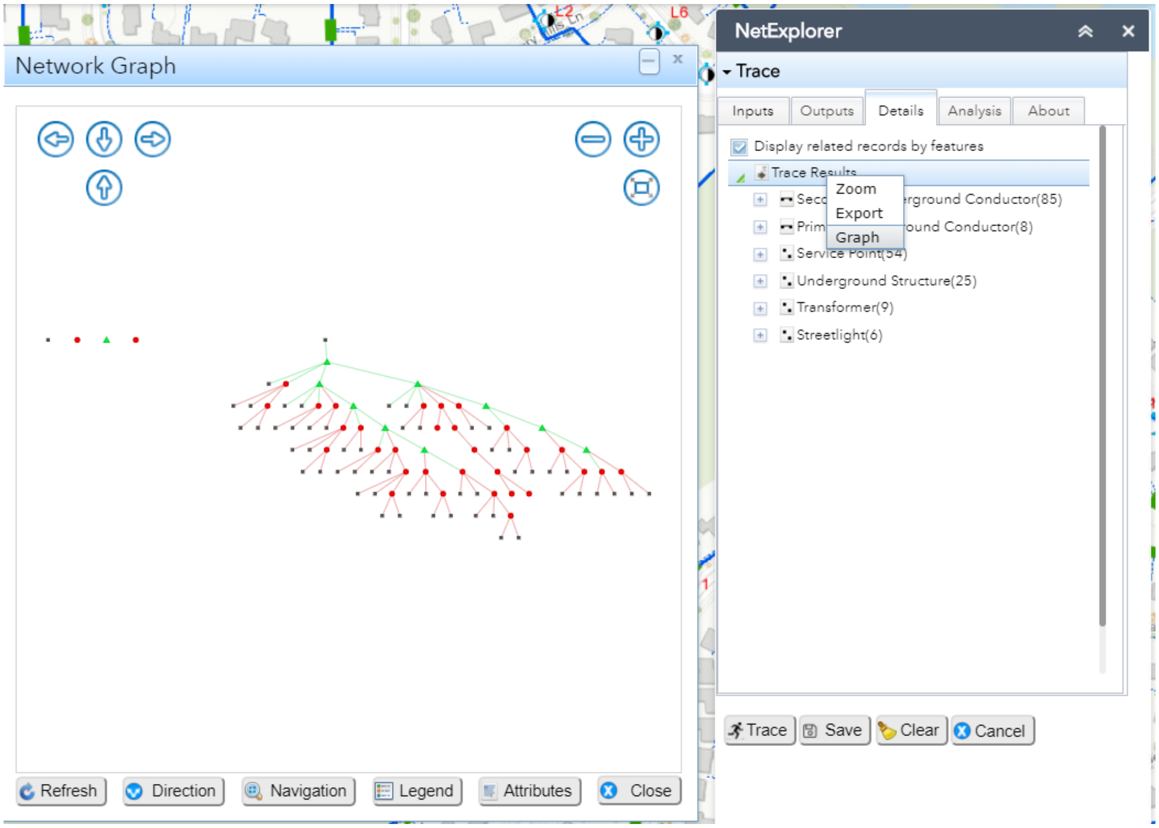


Figure 2-38. Display Trace Results as Graph

This widget also provides user the choice to select the fields of interest compute asset summaries such as length of cable of phase and type, switch count by type, etc. as illustrated in Figure 2-39.

Results Summary

Name	NOMINALVOLTAGE	OPERATINGVOLTAGE	YEARMANUFACTURED	SWITCHSTATUS	SWITCHTYPE	Measure
D Boundary Point	...	...	...	...	...	1
Dynamic Protective Device	...	...	...	...	...	8
Primary Overhead Conductor	...	...	...	...	...	15 | 4187.5 FEET
Primary Underground Conductor	...	...	...	...	...	19 | 5846.4 FEET
Switch	12	12.0 kV	null	Do Not Operate Energized	Switch Position	1
Switch	12	12.0 kV	null	Not Applicable	HOOK STICK	1
Switch	12	12.0 kV	null	null	HOOK STICK	1
Transformer Device	...	...	...	...	...	2
Customer Information	...	...	...	...	...	2

Export Close

Figure 2-39. Summarize Trace Results

2.5.5 Results

Data Model, Data Content, Connectivity and Database

The SDG&E® electric GIS data model, data content, and connectivity based on geometric network technology has many customizations and went through incremental upgrades over the years.

The ArcGIS Utility Network technology offers new modeling capabilities for modernizing the digital model in GIS and leverage the platform capabilities for the Smart eco system use cases. A robust foundation based on current age technology is essential for GIS to integrate with technologies such as Mixed Reality, ADMS, IoT, Machine Learning, Digital Assistant, Drones, etc. to support the following use cases in the future:

- Modeling controlling and communication equipment for DER
- Modeling energy storage equipment
- Integration of secondary voltage data
- Visualization for augmented reality applications
- Inputs and outputs for unmanned aircraft systems

A detailed analysis of the current electric GIS data model was performed to examine the opportunities for modernization, the foundational digital network/connectivity model using ArcGIS Utility Network Management technology. This effort resulted in the identification and testing of following capabilities:

1) Modeling Transmission, Substation and Distribution into contiguous connectivity model
2) Modeling Tiers By Voltage
3) Modeling Asset Groups for Transmission, Substation, Transmission, Telecom and Distribution
4) Modeling Asset Types within each Asset Group
5) Modeling Associations in place of Relationships
6) Modeling Rules for Asset Connectivity and Data Quality
7) Modeling Representative Network Attributes, Categories and Propagators

These modeling optimizations have resulted in a leaner, richer, capable, and performant digital model with 115 asset groups and 160 asset types for SDG&E's electric system. Over 2500 rules matching the current environment were established to govern asset connectivity and manage the integrity of data in the new digital model. This analysis has demonstrated the potential for following improvements in the data model:

1) Up to 85% Reduction in Feature Classes
2) Up to 41% Reduction in Object Classes
3) Up to 90% reduction in Database Relationships
4) Up to 70% reduction in fields

These modeling choices are examined using Utility Network Toolbox in ArcGIS Pro. The Model Manager ArcGIS Pro Add-In illustrated in Figure 2-41 through Figure 2-43. was used for this purpose.

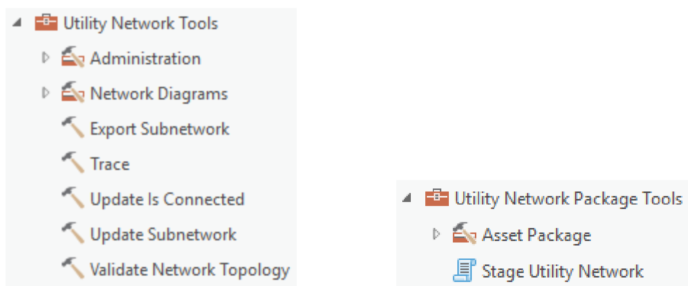


Figure 2-40. ArcGIS Pro Utility Network Toolboxes

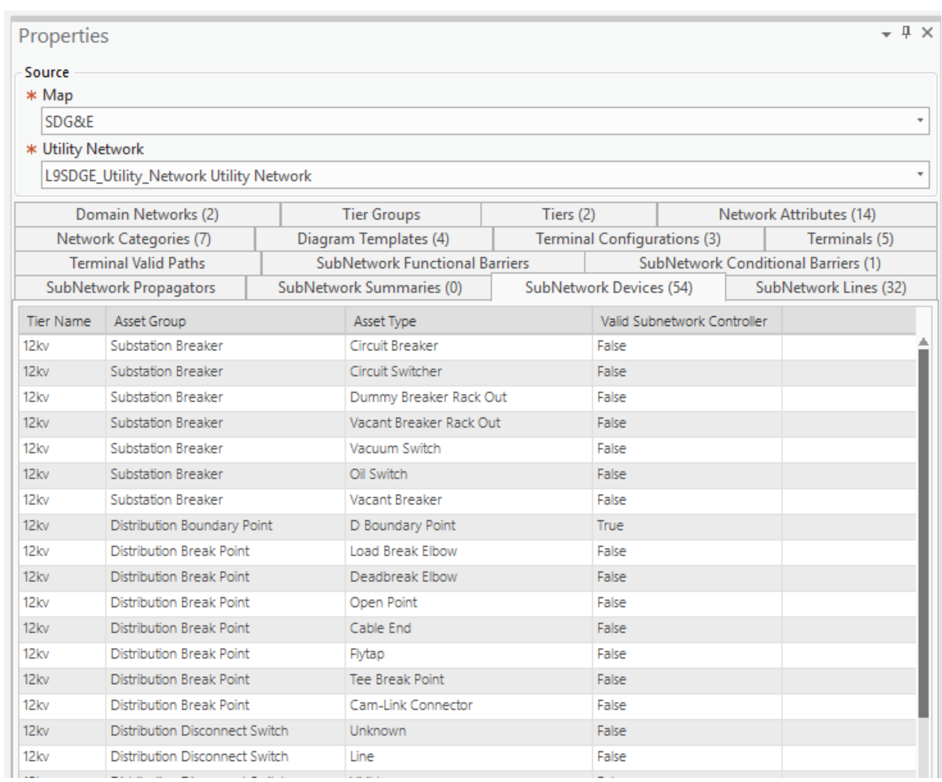
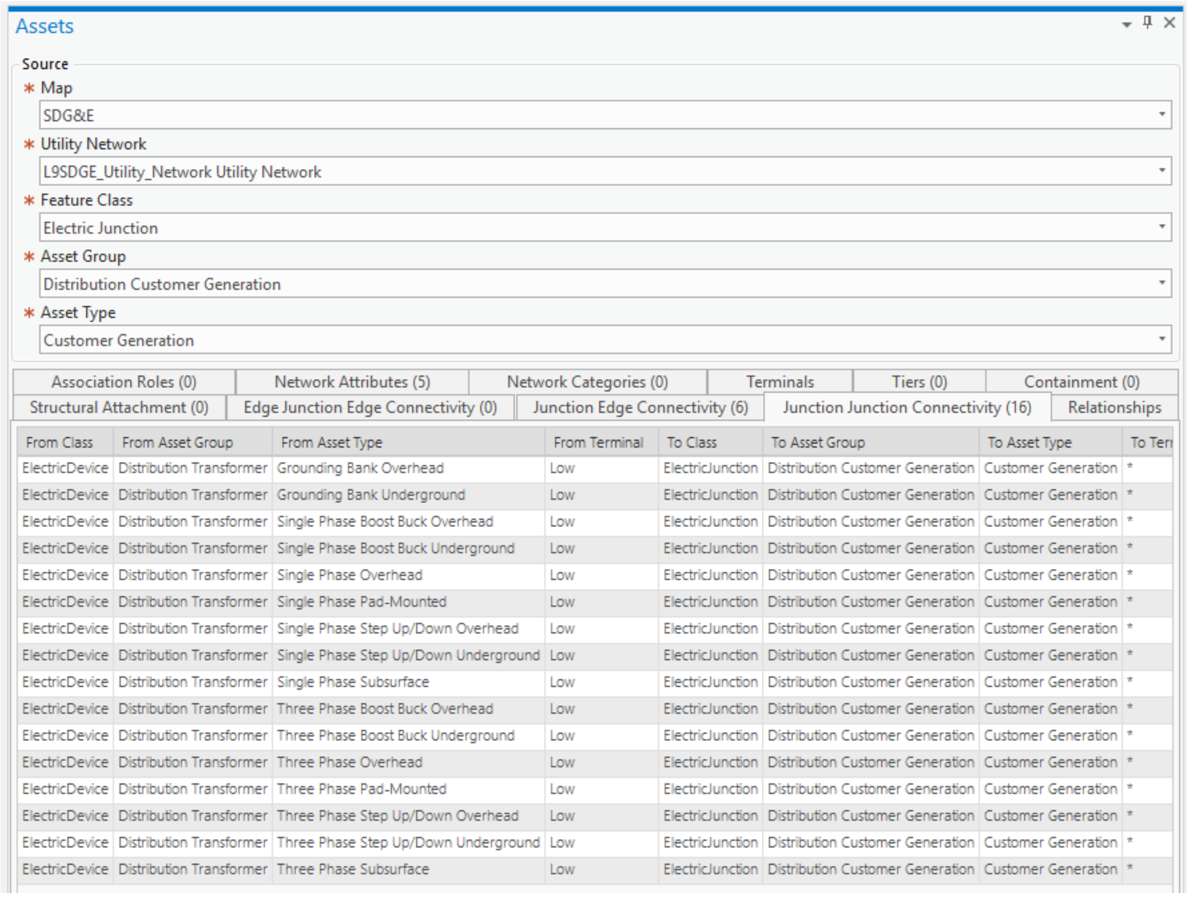


Figure 2-41.Utility Network Properties in Model Manger



From Class	From Asset Group	From Asset Type	From Terminal	To Class	To Asset Group	To Asset Type	To Ter
ElectricDevice	Distribution Transformer	Grounding Bank Overhead	Low	ElectricJunction	Distribution Customer Generation	Customer Generation	*
ElectricDevice	Distribution Transformer	Grounding Bank Underground	Low	ElectricJunction	Distribution Customer Generation	Customer Generation	*
ElectricDevice	Distribution Transformer	Single Phase Boost Buck Overhead	Low	ElectricJunction	Distribution Customer Generation	Customer Generation	*
ElectricDevice	Distribution Transformer	Single Phase Boost Buck Underground	Low	ElectricJunction	Distribution Customer Generation	Customer Generation	*
ElectricDevice	Distribution Transformer	Single Phase Overhead	Low	ElectricJunction	Distribution Customer Generation	Customer Generation	*
ElectricDevice	Distribution Transformer	Single Phase Pad-Mounted	Low	ElectricJunction	Distribution Customer Generation	Customer Generation	*
ElectricDevice	Distribution Transformer	Single Phase Step Up/Down Overhead	Low	ElectricJunction	Distribution Customer Generation	Customer Generation	*
ElectricDevice	Distribution Transformer	Single Phase Step Up/Down Underground	Low	ElectricJunction	Distribution Customer Generation	Customer Generation	*
ElectricDevice	Distribution Transformer	Single Phase Subsurface	Low	ElectricJunction	Distribution Customer Generation	Customer Generation	*
ElectricDevice	Distribution Transformer	Three Phase Boost Buck Overhead	Low	ElectricJunction	Distribution Customer Generation	Customer Generation	*
ElectricDevice	Distribution Transformer	Three Phase Boost Buck Underground	Low	ElectricJunction	Distribution Customer Generation	Customer Generation	*
ElectricDevice	Distribution Transformer	Three Phase Overhead	Low	ElectricJunction	Distribution Customer Generation	Customer Generation	*
ElectricDevice	Distribution Transformer	Three Phase Pad-Mounted	Low	ElectricJunction	Distribution Customer Generation	Customer Generation	*
ElectricDevice	Distribution Transformer	Three Phase Step Up/Down Overhead	Low	ElectricJunction	Distribution Customer Generation	Customer Generation	*
ElectricDevice	Distribution Transformer	Three Phase Step Up/Down Underground	Low	ElectricJunction	Distribution Customer Generation	Customer Generation	*
ElectricDevice	Distribution Transformer	Three Phase Subsurface	Low	ElectricJunction	Distribution Customer Generation	Customer Generation	*

Figure 2-42. Asset Properties viewed in Model Manger

The investigation included the analysis of data loading, viewing, editing, analysis workflows spanning:

1) 16590 Devices
2) 351 Assemblies
3) 24963 Junctions
4) 40464 Line segments
5) 17269 Structures
6) 22817 Structure Line Segments
7) 6 Structure Boundaries

The non-graphical objects in the digital model such as transformer units are modeled as graphical objects that fully participate in the network connectivity. The data model/data modernization workflow illustrated in Figure 2-43 was utilized for creating the visualization model for the distribution circuits and Transmission lines using ArcGIS Toolbox and GN2UN Tool.

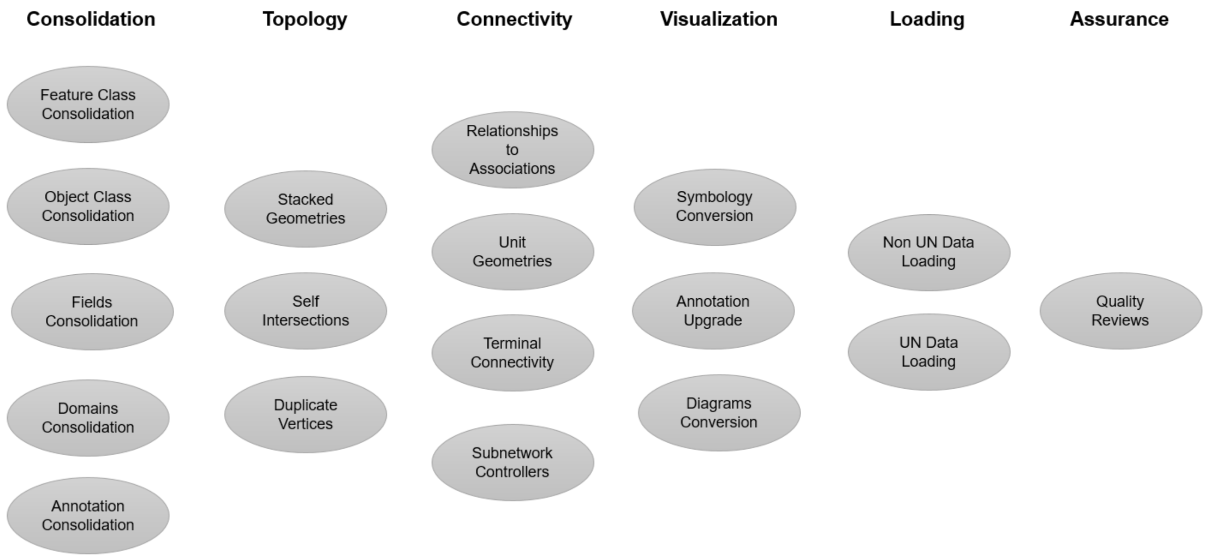


Figure 2-43. Data Model/Data Modernization work flow

2.5.6 Observations, Challenges, and Lessons Learned

<u>Observations</u>

- Modernization of GIS offers following benefits:
    - Robust digital model capable of integrating with technologies such as ADMS, SCADA, IoT, Machine Learning, Virtual Reality, Digital Assistant etc.
    - Out of the box capabilities to perform network editing from web and mobile applications
    - Reduce timelines and operational costs to upgrade to newer releases of GIS software is expected
    - Increased demand on server infrastructure for processing web/feature service loads
    - Reduced demand on virtualization and desktop software
- ArcGIS Utility Network Technology has improved considerably during the course of this investigation. At a minimum, the following capabilities need further examination as the technology continues to offer advancements and choices for:
    - Modeling transmission system
    - Modeling conduits and ducts
    - Modeling and Visualizing As Switched Vs As Built
    - Modeling and Visualizing Active Vs. Prelim
    - Modeling and Visualization Work History
- The technology provides flexibility for phasing the modernization by:
    - View and Analysis Use Cases
    - Desktop Editing Use Cases
    - Web and Mobile Use Cases
    - Integration Use Cases

<u>Challenges and Resolutions</u>

- SDGE will have to perform analysis of new Utility Network models to see what new capabilities can be leveraged and how to migrate existing data model to the new data model. A pilot approach before full-scale implementation is definitely useful.

- Currently, geoprocessing is slow when the new full-facility models are used (some other use cases within this project even used simplifications of the existing, old asset models to speed up rendering to an acceptable level for those use cases, and the new models are significantly more complex, with the corresponding effect on rendering speed). Therefore, an objective of this use case was to assess if and what new virtualization-based HW platform improvements are required to be able, in the future, to configure an environment for SDG&E® users with sufficient performance for GIS rendering of new models.
- The solutions exercised in this use case are based on brand new components (e.g., some of the components are in beta release), with little experience in the industry to draw from.
- This is still a work in progress relative to the larger scope of modernizing SDG&E® GIS infrastructure, but the completed results of this use case have produced initial observations and experiences that will be leveraged in the ongoing efforts on this subject.
- The typical User Experience for Enterprise GIS at SDG&E® scaled solutions has not met user's expectations. With a complex GIS data model utilized at SDG&E®, the application response time has been a known limitation. Moving to next level of using new Esri platforms ArcGIS Pro for building 3D applications will increase workloads for backend processing components such as servers, graphic cards and memory utilization. Using the new system architecture will benefit the performance at enterprise level.
- SDG&E® is still working on establishing the modern architecture. Due to the amount of time required to complete the deployment of servers it is considering as an option for future use. Having explored the limitations, and performance of model architecture through technology vendors, provided scope for SDG&E® to decide on the future for such architecture at SDG&E®.

<u>Lessons Learned</u>

- The electric industry package from Esri served as a good reference. It was not adequate to fully model the SDG&E®electric network.
- This investigation provided opportunity to examine some of the opportunities and the general path for modernization. It also identified the areas that require a deeper analysis to fully quantify and understand the business impact and value for the longer term.
- The ArcGIS Utility Network Technology offers many modeling choices, the evaluation and selection of which requires methodical and diligent analysis of data, applications, interfaces, and user experience center around existing uses cases as well newer use cases focused on spatially driven digital experiences for consumers. Such an effort center around innovation is crucial towards defining the full business value for electric consumers from modernizing GIS.
- Information Technology teams need to understand performance, scaling and system architecture patterns to support the new Esri platforms.
- There are other applications that would benefit from the specialized graphics cards, primarily the PLS CADD and other 3D applications.

3 KEY ACCOMPLISHMENTS AND RECOMMENDATIONS

3.1 Key Accomplishments

With the solutions demonstrated in the project, the SDG&E® project team has made significant improvements over the state-of-the-art approaches at SDG&E® in each of the areas addressed by the five use cases. The following lists some of the key accomplishments of these efforts:

- Real-time feature updates on maps based on the time varying data from PI has been successfully resolved by the use of OSISoft PI Integrator for Esri ArcGIS and Esri GeoEvent Extension for Server products. This mechanism is reusable and has been extensively used across multiple use cases.
- The team has successfully integrated standard and custom PowerBI widgets within various maps, in combination with other feature layers. In the course of the widget development, the emphasis was placed on the widgets' reuse, resulting in a reuse on multiple use cases.
- Electrical circuits layers are extensively used in some of the use cases. The team has found a way of simplifying the asset models of electrical circuits for an improved (better than an order of magnitude) rendering speed of electrical circuits' layers. Where it was taking in excess of 20 seconds to render circuit layers at the beginning of the project, it now takes an acceptable (sub-seconds) time for the same task.
- All use cases have solutions that produce map updates at speeds compatible with expectations of interactive users.
- SDG&E® has completed an initial setup of GIS web applications to host LiDAR data to compliment imagery utilization effort. Ability to use real time data like LiDAR data with GIS data will lead to more effective use and management of these valuable resources in the future.
- SDG&E® has explored 3D utility network modeling and the associated computing infrastructures needed to support eventual widespread use of this advanced modeling approach. This new modeling approach has the potential to reduce the amount GIS models required to achieve this through previous GIS technologies.

SDG&E® is planning to continue with further refinements and extensions of the demonstrated solutions, especially in response to feedback from operational use. Although the basic architectural solutions are believed to be solid, future developments will need to include periodic assessments of the architecture, a search for more robust implementations where possible, and training of future users.

3.2 Recommendations and Insights

Based on the outcomes of pre-production demonstrations, the results for use cases 1, 2, and 3 are being implemented for commercial purposes. Results of use cases 4 and 5 (Imagery Management and GIS Visualization Infrastructure Modernization) have met the objectives set for each of those use cases; however, in both instances, the nature of the research is vast and the efforts are initial steps to establish ground framework for extensive development and investigation (i.e., the cumulative results of use cases 4 and 5 are not ready for production).

In the course of implementation, each of the use case teams had to overcome certain challenges and each has gained valuable insights from doing so. The most notable insights for each use case follow.

UC 1: Transmission Fault Location

- The labor to create the initial reference layers of electric circuits is significant and should be planned for.
- There is a need to setup a process to "re-digitize" electrical circuit lines any time there is a reconfiguration, or to digitize new lines, with an associated process to reflect the changes in PI.

UC 2: Load Curtailment

- From a development perspective, a replacement for the scraping of web pages with a more direct interface would be desirable.
- From a usage standpoint, the development team is expecting quite a bit of feedback from the managers of Emergency Operations Center after a planned demonstration of the function is presented in the near future.

UC 3: AMI for Operations

- Design custom widgets to be as generic as possible. In this project, that approach has proven to be very helpful, and such an approach is expected to continue to be helpful in future projects
- Allowing the application to be customizable by end-users helps better match system functionality with user needs, and ultimately it helps with adoption of the function

UC 4: Imagery Management

- With the processing speed required for LiDAR data analytics and the limitations of GIS as an evolving software in 3D visualizations especially raster or point cloud visualizations presented challenges
- One of the key efforts is to make LiDAR data available through GIS web applications for wide range of audience. Therefore, the LiDAR data is no more a stand-alone dataset, but is an integral part of GIS systems ready to be part of GIS analysis for broader uses and prediction models.

UC 5*: *Visualization Infrastructure Modernization

- Combining high speed processors like NVIDIA GRID GPUs with advanced data models for GIS like UN models will hold future for simplifying the complex relationships between various components of utilities in GIS databases. This opens doors to many possibilities like 3D data models, improved performance of GIS databases etc.

3.3 Technology Transfer Plan for Applying Results into Practice

A primary benefit of the EPIC program is the technology and knowledge sharing that occurs both internally within SDG&E® and across other IOUs, the stakeholder industries and communities. In order to facilitate this knowledge sharing, SDG&E® has been sharing the results of the EPIC SDG&E® Visualization and Situational Awareness Demonstrations project at suitable industry workshops and conferences.

The project team believes that visualization and situational awareness solutions developed in this project will be useful beyond SDG&E®, and, therefore, the solution ideas and lessons learned will continue to be shared with other stakeholders, to promote further advancements of the integration and visualization solutions initiated in this project.

This final report and all other public papers and presentations on this project will continue to be posted on SDG&E's EPIC public website at *www.sdge.com/epic*.

4 CONCLUSIONS

This project examined how data currently unexploited and separately processed at SDG&E® can be integrated and visually presented for strategic use by system operators. The project also demonstrated technical solutions at a pre-commercial level for how data collected from sensors and devices can be processed, combined, and presented to system operators in a way that enhances grid monitoring and situational awareness.

Enhanced monitoring and situational awareness is achieved by providing a geospatial context for a wide variety of operational, historical, and metering data. Consequently, through the numerous use cases undertaken within this project, it has been illustrated how the data commonly used to support diverse business needs at SDG&E® can be combined with geospatial data to significantly enhance insights.

The project has successfully achieved all of its key objectives. In the process, the project team and other SDG&E® stakeholders have gained valuable experience and a solution framework that can be reused to speed up future developments in the area of situational awareness and integration of real-time and geospatial data.

5 METRICS AND VALUE PROPOSITION

5.1 Project Metrics

The project tracking metrics included the milestones in the project plan. Technical project metrics included the completion of the initial specification for a visualization and situational awareness system, the demonstration of a system display mock-up, and the specifications and recommendations regarding adoption by SDG&E®. The primary documentation metric was the delivery of this final report to the California Public Utilities Commission (CPUC).

In addition, major project results were submitted in technical papers and presentations for consideration by major technical conferences and publications.

This section provides more information about the metrics and benefits of the project. The most important benefits are in areas of:

Safety, power quality, and reliability

a. Ability to monitor, visualize, and analyze visualization information can help reduce number of outages, as well as their frequency and duration. Transmission fault location use case is particularly useful for this purpose.
b. Public safety improvement and hazard exposure reduction can also be accomplished by advanced visualization tools. For example, the AMI for operations use case, where the voltage swell, and sag are visually monitored for 19000 smart meters and was increased to 300,000 in Q3 2018. This feature is used for monitoring in emergency scenarios, such as red-flag fire alerts and earthquakes.
c. Improved access and awareness company wide. For example, the load curtailment visualization use case, where the load curtailment is visually represented to help users to visualize the curtailment locations and details as data on map. This feature is expected to be useful in emergencies.
d. Utility worker safety improvement and hazard exposure reduction by improving the access of real-time 3D data to company-wide applications. It will help the field teams to better estimate the field conditions (steep slopes, obstructions etc.) before visits. Imagery management use case was a good demonstration of how LiDAR data can be useful for this purpose. In this use case, SDG&E discovered that between various departments and projects, there are about 7000 LiDAR tiles that can be used in GIS 3D applications.

Identification of barriers or issues resolved that prevented widespread deployment of technology or strategy

a. SDG&E's EPIC visualization infrastructure modernization project was designed to advance the current infrastructure. The EPIC demonstration project's use of new technologies in combination with renewed GIS data models proved to be effective by improving accuracy and reducing data. The project also identified possibilities for creating next generation 3D applications for more reliability and accuracy.
b. The project increased use of cost-effective digital information and control technology to improve reliability, security, and efficiency of the electric grid (PU Code § 8360).
c. The project provided identification and lowering of unreasonable or unnecessary barriers to adoption of smart grid technologies, practices, and services (PU Code § 8360).

Effectiveness of information dissemination

a. The visualization platform enables the creation of numerous reports and fact sheets for various users, not only within SDG&E® but also on a wider basis, via preparation of conference presentations, papers, and other relevant material.

Adoption of EPIC technology, strategy, and research data/results by others

a. The technology demonstrated in the project provides a promising basis for building upon and for development of a commercial version of the monitoring and visualization platform that can be effectively utilized by various stakeholders both at SDG&E® and beyond.

After further development of all presented use cases and additional testing, it would be beneficial to prepare a comprehensive description and documentation of the work and results, to support commercial adoption processes.

5.2 Value Proposition: Primary and Secondary Guiding Principles

The value proposition is to address how the project met the EPIC principals.

Table 5.1 summarizes the specific primary and secondary EPIC Guidelines Principles advanced by the Visualization and Situational Awareness Project.

Table 5.1: EPIC Primary and Secondary Guiding Principles

Primary Principals			Secondary Principals				
Reliability	Lower Costs	Safety	Loading Order	Low-Emission Vehicles / Transportation	Safe, Reliable & Affordable Energy Sources	Economic Development	Efficient Use of Ratepayers Monies
✓	✓	✓	✓		✓	✓	✓

The Visualization and Situational Awareness Project covers the following primary EPIC principals:

- **Reliability:** This project developed tools that give the ability to monitor, visualize, and analyze information which help reduce number of outages, as well as their frequency and duration, giving a higher reliability. Transmission fault location use case is particularly useful for this purpose.

- **Lower Costs:** Given the ability to visualize occurring events in near real time to operators, helps deploy maintenance crews more efficiently and effectively. The imagery management use case, for example, aim is to be able to see the data sources visually, in a geographic context, as opposed to searching for the data via file and folder names. This should save time and effort in organizing huge amounts of data.

- **Safety:** As mentioned, the ability to monitor events and historical trends, like transmission faults or voltage issues, gives the departments and crews that depend on this information, to have a better assessment on how to approach an occurring issue, or based on trends, evaluate on how to safely plan a future activity.

6 APPENDIX: FOUNDATIONAL COMPONENTS

6.1 Esri GIS Components

This section provides very basic information about the Esri GIS components that have been used in this project. The source of the information is largely from Esri's extensive web-help site http://resources.arcgis.com/en/help/ (following the contained links).

Esri provides various solutions to meet its clients' GIS needs. Figure 6-1. Esri ArcGIS Enterprise Components shows the main components of ArcGIS Enterprise, which is the version used by SDG&E® in this project. The diagram shows the main functional groups of components. Subsequent sections contain a brief summary of these groups.

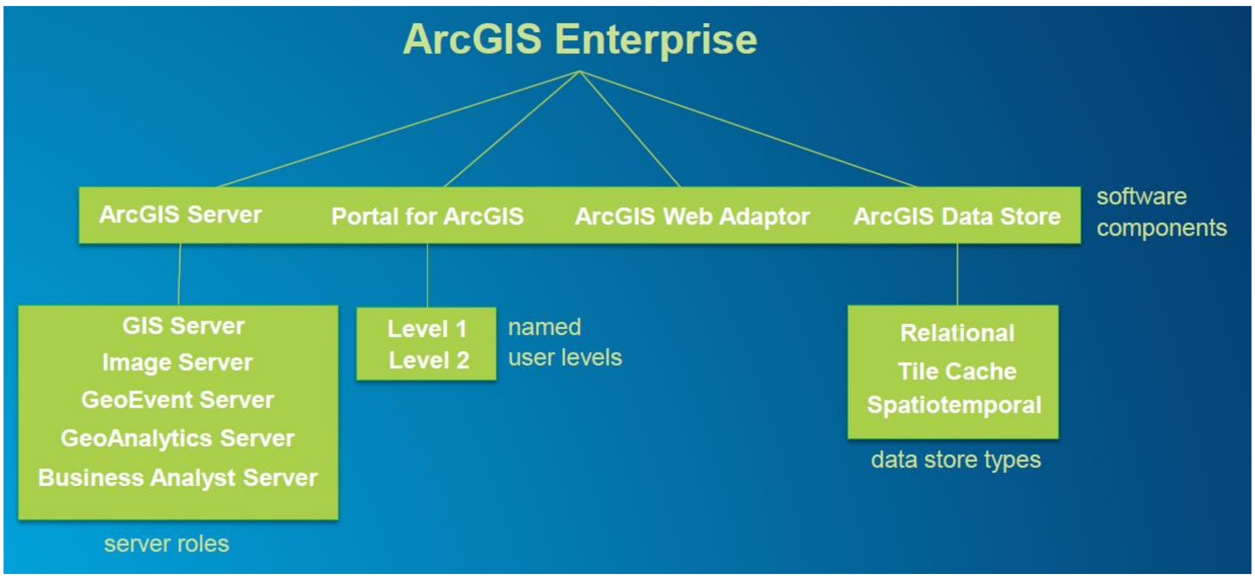


Figure 6-1. Esri ArcGIS Enterprise Components

In the following subsections, each of the functional groups of the ArcGIS Enterprise suite of applications is briefly overviewed based on the information provided on the Esri Web Site.

6.1.1 ArcGIS Servers

There are five different kinds of servers: GIS Server, Image Server, GeoEvent Server, GeoAnalytics Server, and Business Analyst Server. A brief overview of each of these servers is provided in the following subsections.

6.1.1.1 Image Server

ArcGIS Image Server provides serving, processing, analysis, and extracting business value from collections of imagery, rasters, and remotely sensed data. Figure 6-2. Esri Image Server shows, pictorially, Esri's depiction of the main roles of its Image Server. In this project, Image Server is primarily used to support Use Case 4, Imagery Management.

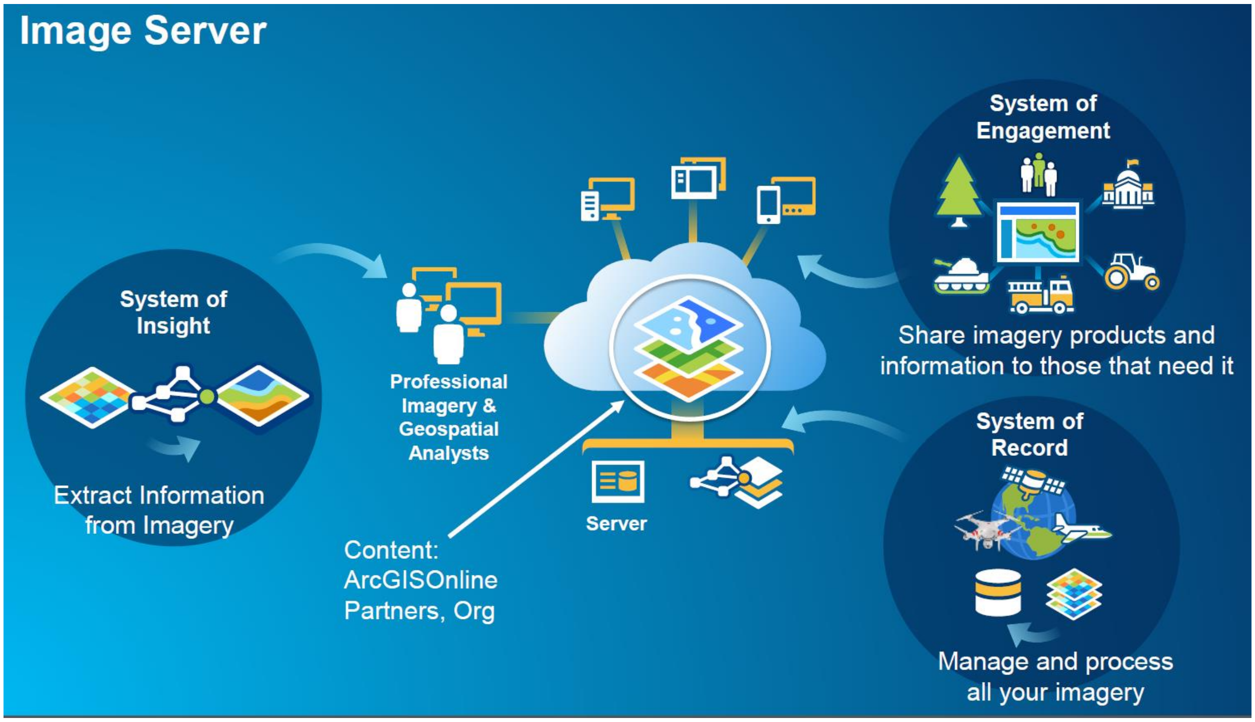


Figure 6-2. Esri Image Server

6.1.1.2 GeoEvent Server

The main role of GeoEvent Server (Figure 6-3) is to facilitate updates of geospatial feature of GIS maps based on dynamic data. Within this project, the role of providing dynamic data updates is filled by OSISoft PI Esri Integrator for the dynamic data that resides in PI Historians, and by GeoEvent Server for all other kinds of dynamic data (e.g., weather, fire, etc.).

6.1.1.3 GeoAnalytics Server and Insights

GeoAnalytics Server (Figure 6-4) supports Big Data analytics on the server side.

Insights provides visual programming capabilities to end-users, allowing them to specify sophisticated data analysis and display results on maps within portal for ArcGIS. Insights blends spatial and non-spatial data to bring together spreadsheets, databases, and ArcGIS data.

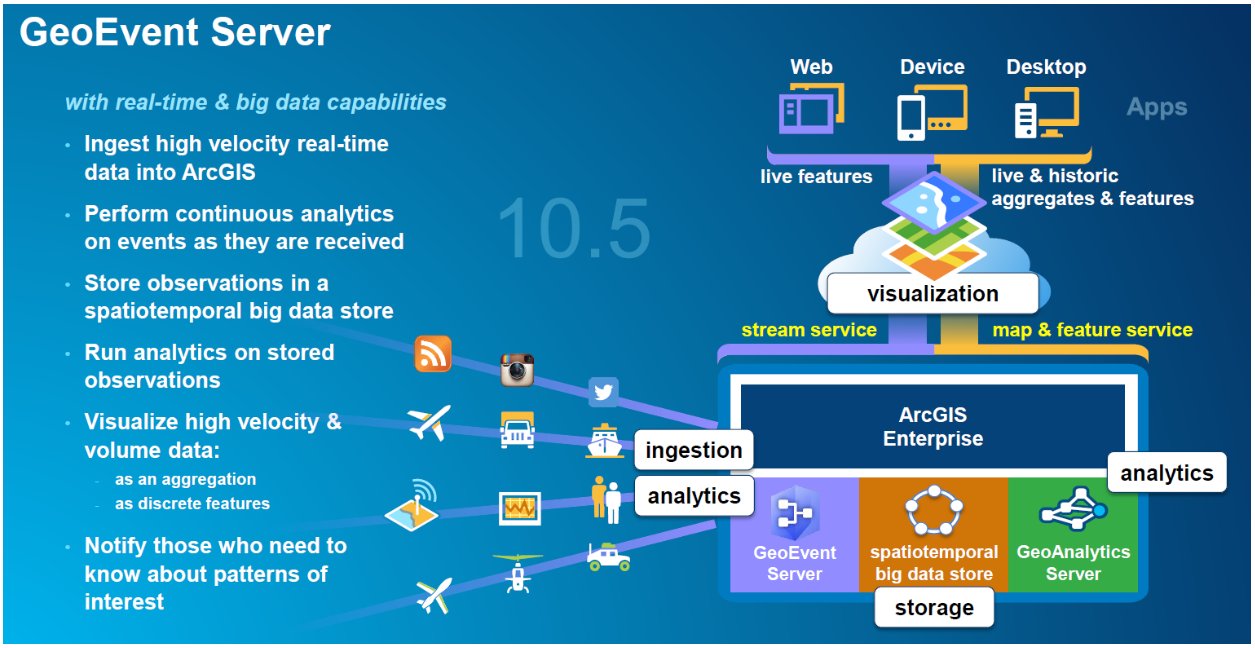


Figure 6-3. Esri GeoEvent Server

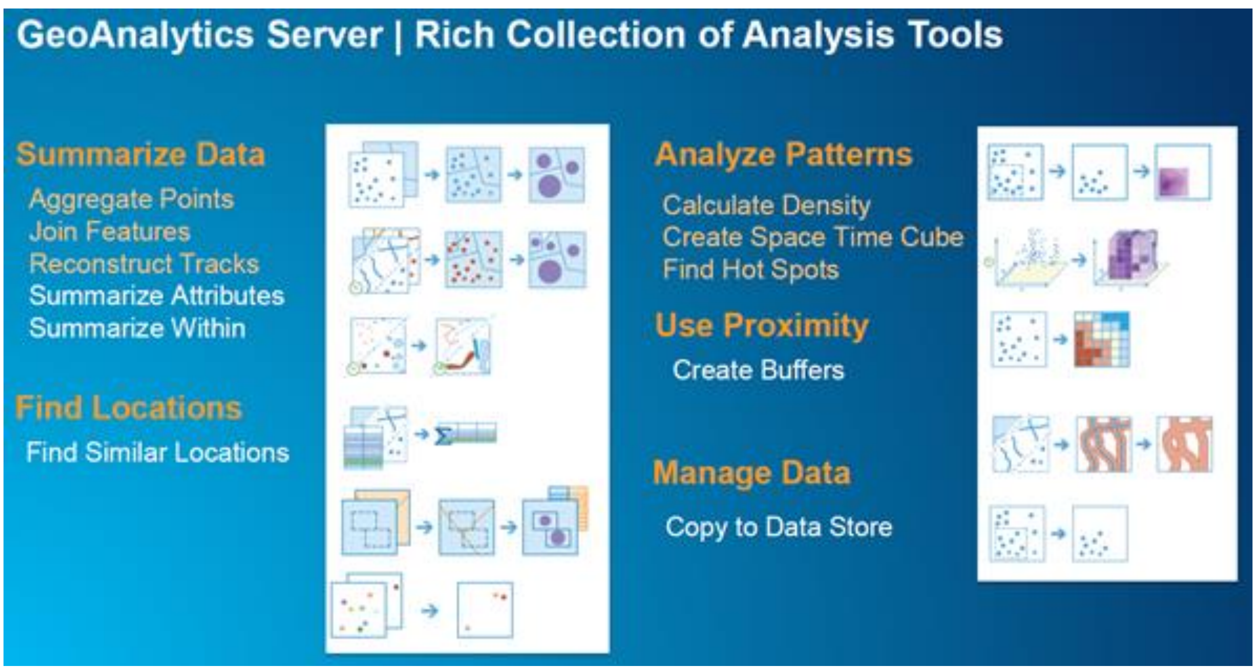


Figure 6-4. Esri GeoAnalytics Server

6.1.2 Portal for ArcGIS

This component was heavily used in this project. Portal for ArcGIS allows sharing of maps, scenes, apps, and other geographic information with other people in the organization. The shareable content is delivered through a website. The website can be customized to the organization's visual standards.

Portal for ArcGIS brings together all the geographic information in the ArcGIS platform, and it shares it throughout the organization. For example, with Portal for ArcGIS it is possible to:

- Create, save, and share web maps and scenes.
- Create and host web mapping apps.
- Search for GIS content within the organization.
- Create groups for sharing GIS information with coworkers.
- Share links to GIS apps.
- Share map and layer packages to use in ArcGIS Desktop.

Portal for ArcGIS includes geographic viewers designed for those who are just beginning with GIS. Experienced GIS users can connect to Portal for ArcGIS from ArcGIS Desktop, developer APIs, and other applications.

6.1.3 ArcGIS Web Adapter

The Web Adaptor provides the following features:

- Allows integration of *Portal for ArcGIS* with the organization's existing web server. Inclusion of a web server with ArcGIS Web Adapter provides the ability to host web applications that use GIS services.
- The organization's identity store and security policies can be used at the web-tier level. For example, when using IIS, it is possible to use Integrated Windows Authentication to restrict who enters the portal. It is also possible to use Public Key Infrastructure (PKI) or any other identity store for which the web server has built-in or extensible support. This allows provision of a single sign-on or other custom authentication experience when logging in to use services, web applications, and Portal for ArcGIS.
- Portal for ArcGIS functions can be exposed through a site name other than the default ArcGIS.

The Web Adaptor is platform independent of Portal for ArcGIS, and hence, the Web Adaptor does not have to match the operating system platform of the portal. For example, if the portal is running on Linux, it is possible to deploy ArcGIS Web Adaptor (IIS) or (Java Platform) to work with Portal for ArcGIS. Conversely if the portal is running on Windows, an ArcGIS Web Adaptor (Java Platform) on Linux can work with the Portal for ArcGIS.

After installing and configuring the Web Adaptor, the URL used to access the portal will be in the format https://webadaptor.domain.com/arcgis/home. For example, if the machine hosting the Web Adaptor is named *webadapter* with the domain *sdgeorg.net*, and the portal is named *arcgisportal*, the portal is accessed using the URL https://webadapter.sdgeorg.net/arcgisportal/home.

6.1.4 ArcGIS Desktop and Server

ArcGIS for Desktop – Comprehensive software used by GIS professionals on Windows PCs for a range of GIS activities including data compilation, mapping, modeling, spatial analysis, and geoprocessing. ArcGIS for Desktop extensions provide additional functionality such as 3D visualization, network analysis, schematics, and geostatistics. Desktop is the starting point and foundation for deploying GIS in organizations. It is used by professional GIS staff for desktop mapping, reporting, and analysis. It is also used by data compilation staff to create and maintain critical foundational data layers that fuel other GIS applications. This role for data stewardship is quite significant.

ArcGIS for Server – GIS back-office software that enables centralized, enterprise-level geodatabase management and server-based publication of maps and geographic information services throughout the enterprise and on the Internet as web services. ArcGIS Server supports the leading enterprise database management systems (DBMS): Oracle, SQL Server, DB2, Informix, and PostgreSQL. It is available on Windows or Linux servers on-site or in cloud configurations. This project uses on premises installations.

ArcGIS Server provides the core technology for implementing large-scale GIS in organizations and businesses worldwide.

6.1.5 Esri Utility Network

A utility network is the main component used for managing utility and telecom networks within ArcGIS. Combined with a service-based transaction model, attribute rules, editing tools, and more, it allows users to completely model and analyze their complex network systems for water, gas, electric, telecom, sewer, storm water, and other utilities.

The capabilities to manage and analyze network data are delivered through the ArcGIS Utility Network Management extension to ArcGIS Enterprise. The extension provides the ability to access all capabilities through a service-based architecture callable from any device or application that supports web services.

A utility network is a comprehensive framework of functionality in ArcGIS for modeling utility systems such as electric, gas, water, storm water, wastewater, and telecommunications. It is designed to model all of the components that make up utilities system—such as wires, pipes, valves, zones, devices, and circuits—and allows you to build real-world behavior into the features you model. The key elements of the Utility Network platform are shown in Figure 6-5

Figure 6-5. Esri Utility Network System Components

6.1.6 ArcGIS Data Store

ArcGIS Data Store is an application supporting configuration of data stores for hosting and for federated servers used with the Portal. The following different types of data stores can be configured:

- Relational data store: stores Portal's hosted feature layer data, including hosted feature layers created as output from spatial analysis tools running in the portal
- Tile cache data store: stores caches for Portal's hosted scene layers
- Spatiotemporal big data store: archives real-time observation data that can be used with an ArcGIS Server running ArcGIS GeoEvent Server that is federated with the portal; also stores the results generated using ArcGIS GeoAnalytics Server tools

A more comprehensive list of ArcGIS data store features includes:

- Publish large numbers of hosted feature layers.

  When publishing large numbers (thousands) of feature layers to Portal, it is recommended to use ArcGIS data store to create a relational data store. Hosted feature layers that rely on the relational data store require a smaller memory footprint to run, making it possible to publish many services with fewer hardware resources.
- Publish hosted scene layers to the Portal.

  When the Portal's hosting server is registered with a tile cache data store, it is possible to publish hosted scene layers from ArcGIS Pro to Portal.
- Publishing hosted scene layers also creates a hosted feature layer. Esri recommends use of ArcGIS data store to create a relational data store to support this functionality; other managed databases registered with the hosting server can be used instead if preferred.
- Archiving high volume, real-time observation data
- When using ArcGIS GeoEvent Extension to stream high volumes of real-time data, it is possible to create a spatiotemporal big data store to archive the GeoEvent observation data in it
- Create automatic backups of relational data stores
- Backups support recovery of feature data in the event of a disaster such as data corruption or hardware failure
- Configure a failover data stores for feature layer data and scene caches
- ArcGIS data store allows a setup of primary and standby relational data store machines, and primary and standby tile cache machines. Hosted feature layer and hosted scene layer tile cache data is replicated from the primary machines to the standby machines
- Configure highly available spatiotemporal big data stores
- Configure multiple spatiotemporal big data stores to balance data loads over multiple machines and ensure availability of spatiotemporal data in the event of a machine failure.
- Analyze the Portal for ArcGIS map viewer
- Spatial analysis functionality in Portal requires that the portal hosting servers use an ArcGIS relational data store
- GeoAnalytics Tools require the hosting server to be configured with a spatiotemporal big data store.

6.2 OSIsoft PI

OSIsoft PI was originally developed to efficiently capture and store real-time data, especially time series data. Through addition of functions, and a widespread deployment in the industry, it has grown to now include a comprehensive set of functions to capture, process, analyze, store, and visualize any form of real-time data. PI is used extensively at SDG&E®.

The key elements of the PI platform are shown in Figure 6-6. A standard installation is shown in Figure 6-7.

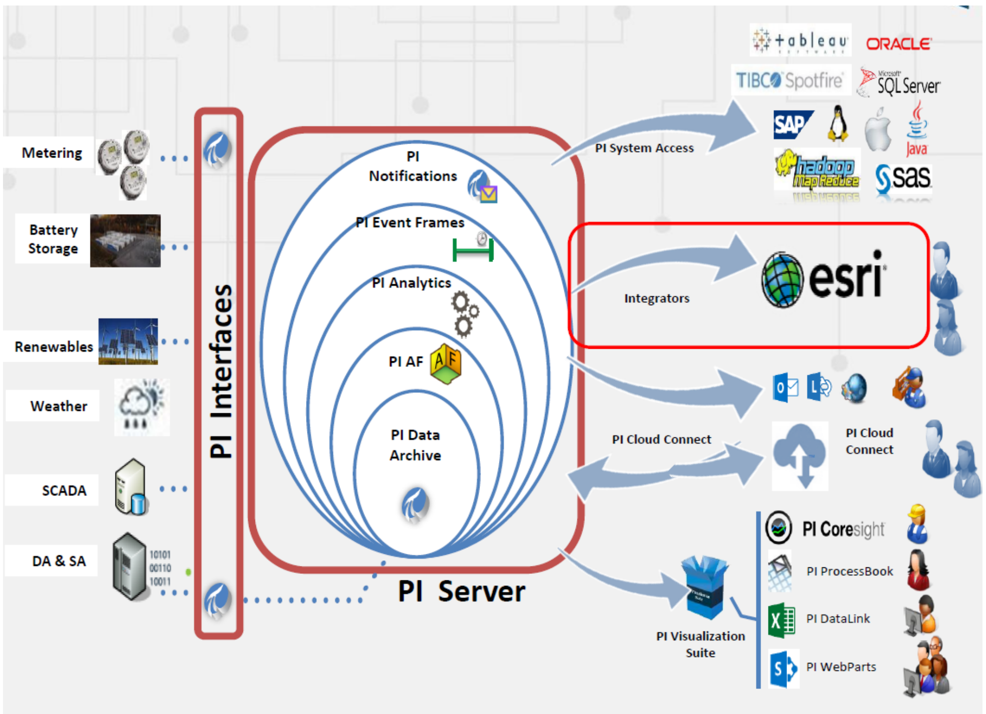


Figure 6-6. OSISoft PI System Components

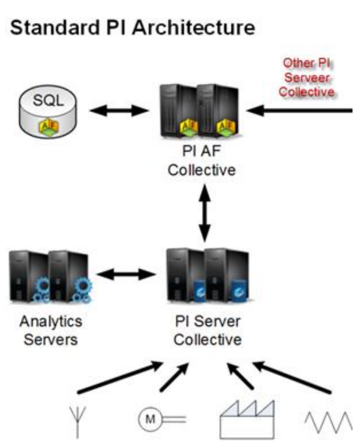


Figure 6-7. OSISoft Standard PI Architecture

A generic on-premises installation of PI systems in combination with ArcGIS is shown in Figure 6-8 and the specific configuration at SDG&E® is shown towards the beginning of this document in Figure 1-1. Main Components of Visualization and Situational Awareness DemonstrationFigure 1-1

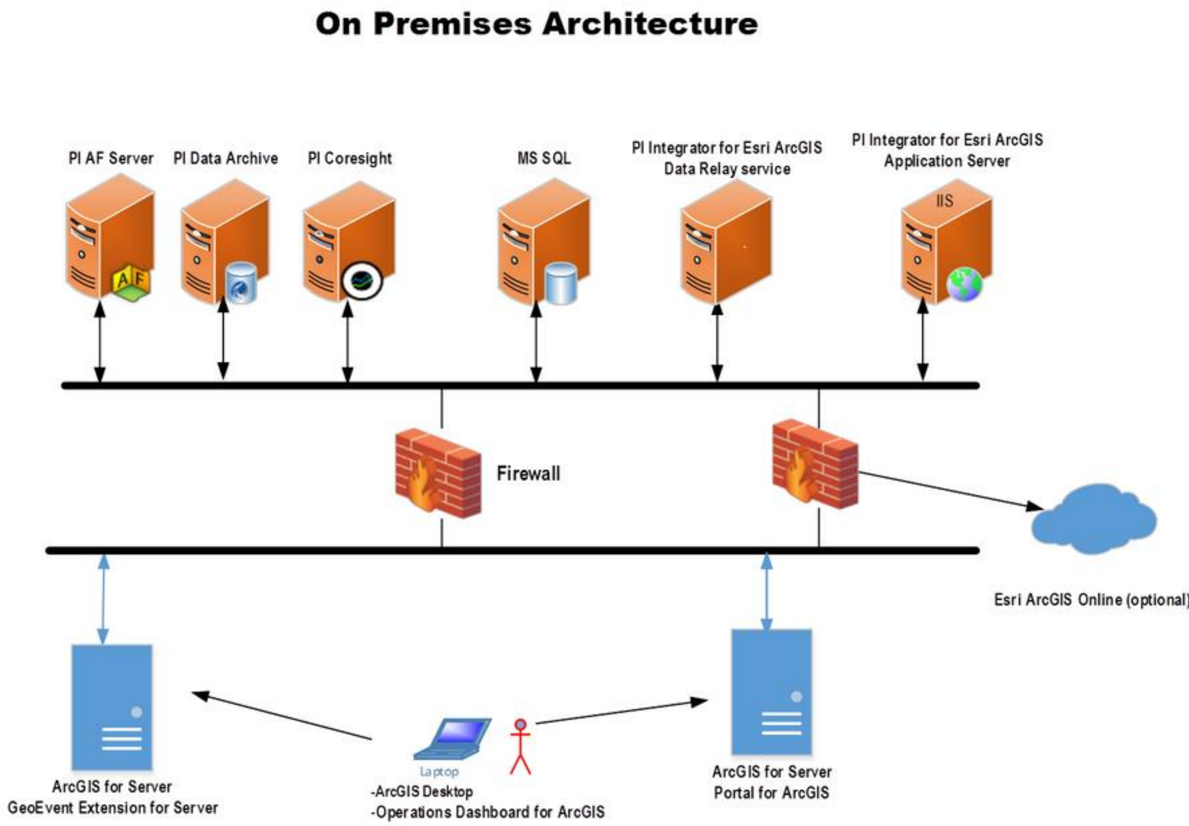


Figure 6-8. OSISoft Generic On-Premises Architecture

6.2.1 PI Integrator for Esri® ArcGIS® Overview

PI Integrator for Esri® ArcGIS® is the OSISoft product that enables a PI System to be connected with an ArcGIS Platform to first define geospatial feature services and layers in ArcGIS, and once defined, to dynamically update these with the data from PI[4]. The whole process of dynamically updating ArcGIS feature services and layers requires two components from Esri and two components from OSISoft:

- Esri
  - Esri ArcGIS for Server: manages feature services and layers
  - GeoEvent Extension for Server: provides GeoEvent Service to update real-time data, as well as Input and Output (the difference between the input and output is that additional processing can be performed on Input data within the GeoEvent Service, e.g., filtering, processing, geofencing, to produce Output)
- OSISoft
  - PI Server, containing PI Data Archive and PI Asset Framework data stores

[4] https://www.youtube.com/watch?v=7iTPdVHZkWM

- PI Integrator for Esri ArcGIS, containing Application Server and Data Relay

The integration process starts by using Application Server wizards to setup GeoEvent Services and Inputs and Outputs in GeoEvent Extension for Server. A simple setup is when Output = Input, but manual changes in GeoEvent Extension for Server can be made to institute additional transformation of Input data to Output. Here, one service is defined for each PI AF Template used.

Once the GeoEvent Service is defined, at certain periodicity, the service issues HTTP (or HTTPS) to Application Server, which in turn relies on Data Relay to retrieve data from PI Data Archive referenced by an AF Template, provides it to Application Server, which in turn responds to GeoEvent Service with the requested data, which then traverses through Input to Output within GeoEvent Extension for Server, and finally updates the Feature Service on ArcGIS for Server.

The Data Relay component sends metadata and real-time information to Application Server of Esri ArcGIS.

6.3 Power BI

Power BI is a Microsoft suite of tools for efficient data analysis, which enables users to connect with many data sources to extract, analyze, and visualize the extracted data in many different ways. Once a connection to data sources is established, even the end users – without any programming skills – can specify through a Graphical User Interface (GUI) the type of analysis to be performed, and how to visualize the data and the results. Enhanced capabilities for these tasks are also available through high-level languages supported by the various Power BI sub-components.

Esri provides a component that enables display of Power BI results on geo-spatial maps, giving additional options for presenting results in addition to Excel-like tables and graphs that are available in the Power BI itself. This component, however, does not work in mixed environments, where Esri products run on premises and Power BI in the cloud, as is the case at SDG&E®. To overcome this difficulty, SDG&E® resorted to Java-based programming to allow Power BI widgets to be displayed on geospatial maps.

Major sub-components of Power BI (with yes/no indication of if used in this project):

- Power Query (yes): Data mash up and transformation tool.
- Power Pivot (yes): In-memory tabular data modelling tool
- Power View (yes): Data visualization tool
- Power Map (no): 3D Geo-spatial data visualization tool
- Power Q&A (no): Natural language question and answering engine
- Power BI Desktop (yes): A development tool for building Power BI reports and dashboards

There are other components, such as PowerBI.com Website that is used to share Power BI data analysis as cloud services; and Power BI Mobile Apps on Android, Apple, and Windows mobile devices.

A Sempra Energy utility®

EPIC Final Report

Program	**Electric Program Investment Charge (EPIC)**
Administrator	**San Diego Gas & Electric Company®**
Project Number	**EPIC-1, Project 2**
Project Name	**Visualization and Situational Awareness Demonstrations**
Module Name	**Module 3, Unmanned Aircraft Systems for Advanced Image Collection and Analytics**
Date	**October 4, 2018**

Attribution

This comprehensive final report documents the work done in this EPIC project. The project team for this work included the following individuals from SDG&E®, listed alphabetically by last name.

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The project team also included representatives of the following organizations:

GIS Surveyors Inc. (GSI)
Exelis Visual Information Solutions Inc.
GeoDigital International Inc.

Executive Summary

This summary provides an overview Module 3 of SDG&E's Project 2 on "Visualization and Situational Awareness Demonstrations", which was funded by the first triennial cycle of the Electric Program Investment Charge (EPIC-1). The objectives of Project 2 were:

- Examine how data currently unexploited and separately processed can be integrated and visually presented for strategic use by system operators.
- Demonstrate how data collected from sensors and devices can be processed, combined, and presented to system operators in a way that enhances utility system monitoring and situational awareness.

Module 3 of this project explored how Unmanned Aircraft Systems (UAS) can be used for advanced image collection, ingestion and storage of UAS data, and how advanced data analytics could be conducted through means of a platform especially adapted to meet SDG&E's organizational requirements. A common theme identified by SDG&E stakeholders was the lack of a single, centralized data repository to store, visualize and analyze the large quantities of data collected by SDG&E. Currently, stakeholder groups collect, ingest, manage and maintain their own data resulting in little to no data sharing capability.

The stakeholder requirements were split into the following groups: Infrastructure, Vegetation Management and Environmental Services. The following test cases were demonstrated:

Infrastructure

1. Implementation of a Centralized Repository for Data Management
   Demonstrate how the vendor tool could be used as a centralized repository for full data lifecycle management for design and construction projects.
2. Export Results for Downstream System Integration with GIS
   Demonstrate how the vendor tool could be integrated with SDG&E's in-house GIS system.

Vegetation Management

3. Identifying Tree Growth Patterns
   Evaluate how advanced data analytics can be used to make tree growth forecasts to assist SDG&E in planning tree maintenance and cutting works.

4. Identifying Areas of Tree Health

   Explore how advanced data analytics can be used to assess tree health. Dead and dying trees can pose a severe fire risk and must be managed according to industry standards.

5. Identifying Changes in Pole Lean

   Identify poles that have begun to lean through advanced data analytics. Identifying leaning poles allows rectification works to be conducted and reduces non-compliances.

6. Maintenance Audit

   Evaluate how advanced data analytics can be used to check that maintenance works have been completed on schedule and per the required specifications.

Environmental Services

7. Identification of Water Bodies

   Demonstrate how advanced analytics can be used to calculate the proximity of an existing and/or proposed pole site with a body of water.

8. Pole Accessibility from Roadway

   Demonstrate how advanced data analytics can be used calculate the distance from a roadway to a pole and determine the type of terrain in between.

9. Capture of Pole Accessibility Field Notes

   Demonstrate how the vendor system's mobile capability can be used to capture pole accessibility notes whilst out in the field.

The work demonstrated the value of having a central repository to store, catalog, and sort data that could be visualized by multiple stakeholders concurrently. It allows the stakeholders to create custom views for their area of operations and to perform deep learning analytics on the vast amount of data to provide actionable results to important test cases, ranging from automatic identification of equipment on poles to tracking vegetation encroachment on power lines.

These are just some of the use cases that the data captured from UAS will enable stakeholders to leverage. All these scenarios will enable the utilities to perform virtual asset inspection that enhances safety and reliability of power system equipment. Additional evaluation is recommended before making decisions about commercial deployment of any specific data management platform.

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Abbreviations & Acronyms

Acronym	Definition
API	Application Programming Interface
ASD	Aviation Services Department
ASPRS	American Society for Photogrammetry and Remote Sensing
CMP	Corrective Maintenance Program
CPU	Central Processing Unit
CPUC	California Public Utilities Commission
CSV	Comma Separated Values
DEM	Digital Elevation Model
DSM	Data Source Modeler
DWG	AutoCAD Drawing Database file
DXF	Drawing Exchange Format
EA	Enterprise Architecture
EPIC	Electric Program Investment Charge
EPP	Environmental Project Planning
ESPG	European Petroleum Survey Group
ESRI	Environmental Systems Research Institute
ETS	Environmental Tracking System
EXIF	Exchangeable Image File
FiRM	Fire Risk Mitigation
FTP	Fire Transfer Protocol
GB	Gigabyte
GHz	Gigahertz
GIS	Geographic Information System
GPS	Global Positioning System
GPU	Graphics Processing Unit
IR	Infrared
IT	Information Technology
JSON	JavaScript Object Notation
KMZ	Keyhole Markup Language Zipped files
kV	Kilovolt
LAS	Log ASCII Standard
LiDAR	Light Imaging Detection and Ranging

MB	Megabyte
MVCD	Minimum Vegetation Clearance Distance
NIST	National Institute of Standards and Technology
OGC	Open Geospatial Consortium
PC	Personal Computer
PDF	Portable Document Format
PG&E	Pacific Gas and Electric
PIDS	Pole Information Data System
PLS-CADD	Power Line Systems - Computer Aided Design and Drafting
QC	Quality Control
RAM	Random Access Memory
RANSAC	Random Sample Consensus
RBAC	Role-Based Access Control
RGB	Red, Green, Blue
ROV	Remotely Operated Vehicle
SCE	Southern California Edison
SDG&E	San Diego Gas & Electric
SMART	Specific, Measurable, Achievable, Realistic, Timely
SME	Subject Matter Expert
SoCalGas	Southern California Gas
SSL	Secure Sockets Layer
TCM	Transmission Construction and Maintenance
TCP/IP	Transmission Control Protocol/Internet Protocol
TED	Transmission Engineering and Design
TLS	Transport Layer Security
UAS	Unmanned Aircraft System
USGS	United States Geological Survey
UV	Ultraviolet
WFS	Web Feature Services
WMS	Web Map Services
XLS	Microsoft Excel Spreadsheet file

1.0 Introduction

The California Public Utilities Commission (CPUC) established the Electric Program Investment Charge (EPIC) to provide public interest investments in research and development of clean energy technologies.

This report documents the work done in Module 3 of SDG&E's Project 2 (Visualization and Situational Awareness Demonstrations) in the first EPIC triennial cycle (EPIC-1). For more background on the structure and requirements of EPIC and on SDG&E's EPIC projects, the reader is referred to the SDG&E public EPIC website.[1]

The objectives of EPIC-1, Project 2 were:

- Examine how data currently unexploited and separately processed can be integrated and visually presented for strategic use by system operators
- Demonstrate how data collected from sensors and devices can be processed, combined, and presented to system operators in a way that enhances utility system monitoring and situational awareness

1.1 Focus of Module 3 of EPIC-1, Project 2

This module of the project focused on pre-commercial demonstrations of vendor tools to investigate the benefits of advanced data analytics conducted on LiDAR and imagery data collected via Unmanned Aircraft Systems (UAS). The knowledge created in the demonstrations was intended for use in decision making regarding what prospective solutions might be adopted commercially.

Several stakeholder meetings took place to discuss inefficiencies with their current workflows and to determine how these inefficiencies could be mitigated by introducing advanced data analytics and improved data collection techniques by utilizing UAS data.

[1] SDG&E Electric Program Investment Charge (EPIC) website found at www.sdge.com/EPIC

Thought was also given to how this collected data could be ingested, stored, visualized and retained on a single centralized repository to improve data sharing between stakeholder groups.

The overall goal was to identify process improvements which can result in reduced costs, process efficiency, heightened resource productivity, improved safety and electricity ratepayer benefits for customers.

Two vendors were selected to conduct the advanced data analytics and demonstrate how their platforms can manage this data in a centralized repository throughout the full data lifecycle. These vendors will be referred to as Vendor A and Vendor B throughout this report.

1.2 Project Task Summary

The project was split into five distinct task phases. The following is a description of each phase of work assigned to the EPIC Project Team and the expected deliverables.

Task 1 - Project Kickoff and Work Plan

- Develop final report outline based on interaction with SDG&E, vendors, EPIC guidelines and overall project tasks
- Create project timeline showing key milestones and high-level tasks
- Develop stakeholder and use case information forms for use in the one-to-one stakeholder use case meetings
- Attend and compile summaries of the vendor kick-off meetings

Deliverables:

1. Final report outline
2. Project timeline
3. Stakeholder information form
4. Use case information form
5. Vendor kickoff meeting summaries

Task 2 - Use Case Development

- Conduct one-to-one meetings with each of the participating stakeholders and vendors to develop use cases that define visualization and situational awareness using the proposed vendor test system
- Define stakeholder group responsibilities
- Work closely with the stakeholders and vendors to define use cases that are SMART (Specific, Measurable, Achievable, Realistic, Timely)
- Create workflow diagrams for each use case that define visualization and situational awareness using the proposed test system and document the requirements for data usage and ingestion including existing workflows and file types
- Compile the findings from stakeholder meetings, determine conflicts, technology limitations and data overlap between stakeholders. Identify current data management systems and requirements for data ingestion, security and size limitations and end user needs; working interactively with the SDG&E EPIC project team, IT management, GIS, Aviation Services, and other participating stakeholders
- Develop a requirement traceability matrix including functional, technical, applicable standards, information systems/technology and security related requirements
- Provide a Task 2 report including use case summaries, existing stakeholder workflows, requirement traceability matrix, use cases, test plan and test cases
- Assist SDG&E's project team to select and prepare the baseline dataset or test circuit, and participate in collection of sample data to be given to the vendor, if a test circuit is chosen

Deliverables:

1. Summary of stakeholder group responsibilities
2. Summary of use cases
3. Use case workflow diagrams
4. Summary of requirements (functional, technical, information technology and security) and traceability matrix
5. Summary of test cases
6. Test case workflow diagrams

Task 3 - Test System Design, Development and Setup

- Describe the selected baseline dataset or test circuit data. Vendors provided high level system requirements for each of the vendor tools taking into consideration the test cases developed in Task 2, for comment and review
- Vendors provided a high-level system architecture diagram that illustrates basic building blocks, for comment and review
- Summarize and compare vendor tool design, basic architecture and system setup
- Develop high-level system design requirements for a prospective SDG&E system, agnostic of vendor, generated from the list of use cases identified in Task 2

Deliverables:

1. Baseline dataset outline
2. Evaluation of high-level vendor tool system requirements specification provided by vendor
3. Evaluation of vendor tool architecture diagrams provided by vendor
4. Summary and comparison of overall vendor tool design, architecture and setup
5. Draft high-level system design requirements for a prospective SDG&E system agnostic of vendor, based on the use cases identified in Task 2
6. Proposed system design recommendations for SDG&E

Task 4 - Evaluate Test System Demonstrations

- Perform system demonstrations, assist in testing (if applicable) and provide feedback on vendor tools and end user ingestion of data sets
- Collate demonstration feedback from stakeholders
- Review and analyze vendor ability to demonstrate selected test cases
- Report on vendor test case results and evaluate accuracy and confidence of findings
- Compare and summarize overall vendor tool abilities and user experience
- Expand high-level system design requirements based on what was demonstrated by the vendors

Deliverables:

1. Summary and comparison of stakeholder feedback
2. Summary and comparison of vendor test case results
3. Summary and comparison of overall vendor tool abilities and user experience
4. Proposed system design recommendations for SDG&E
5. Final high-level system design requirements prospective SDG&E system

Task 5 - Comprehensive Final Report

- Prepare a comprehensive final report that states the project objective (from the CPUC approved SDG&E application for EPIC-1), explains the relationship to state policies and industry needs, estimates the project success using predetermined metrics, describes the work performed, provides key test results and data analysis of test results, and provides the key findings, conclusions, and recommendations regarding possible commercial adoption of the methods and tools that were demonstrated. A standalone executive summary shall also be prepared. The executive summary shall not exceed two pages and shall be placed in the front of the final report. Work with SDG&E to develop an outline agreed upon in Task 1
- The report shall be of high professional and editorial quality including internal and external review and editing cycles, and shall follow the required outline developed in the project plan, and it shall adhere to EPIC guidelines. The graphics used in the report shall be high quality and high legibility
- Input shall be obtained from the SDG&E project team in preparing the report in draft form for review by the SDG&E stakeholder review panel
- The report must be revised into final form based on comments from the stakeholder review panel
- The Contractor shall submit the final report to SDG&E for review. SDG&E will file the final report with the CPUC and make available to the public
- Prepare a final PowerPoint presentation on the work

Deliverables:

1. Comprehensive final report, both hard and electronic copies

2. Final PowerPoint presentation on the work to be presented to all stakeholders at the end of the project

2.0 Stakeholder Analysis

SDG&E stakeholders were identified by EPIC project leadership for participation based on their interest in the project and the benefits that could flow from the implementation of advanced data analytics on LiDAR and imagery collected via Unmanned Aircraft Systems (UAS).

Representatives from the following stakeholder teams were selected for input in the kick-off meetings to discuss potential use cases: Aviation Services, Infrastructure, GIS, Reliability, Architecture, FiRM Program, Vegetation Management, Environmental Services and Land Management. The vendors also attended these meetings, which allowed them to gain an initial understanding of the issues faced by each stakeholder and what obstacles they were looking to overcome.

To make efficient use of the stakeholders' time and availability, the stakeholder representatives were split into the following 'buckets': Infrastructure, Vegetation Management and Environmental Services. Meetings were arranged between the stakeholder groups and vendors to further develop the use cases and narrow down the test case selection, that met the requirements in terms of the data set provided, cost and time.

This section describes the overall stakeholder group responsibilities and the inefficiencies they face when conducting their day to day business.

2.1 Infrastructure Stakeholder Group

2.1.1 Responsibilities

The 'Infrastructure' stakeholder group is made up of the Information Technology, Aviation Services and Enterprise Architecture Departments. Each team has its own set of roles and responsibilities which are outlined below.

Information Technology (IT)

The Information Technology Department (IT) is accountable for the architecture, hardware, software and networking of computers across SDG&E. Key responsibilities include programming, technical support, system administration, data management and security.

Aviation Services Department (ASD)

The Aviation Services Department (ASD) utilize UAS and helicopters to capture data at the request of other stakeholders. Currently, they can deliver Red, Green, Blue (RGB) imagery and video, LiDAR and Infrared (IR) data sets at relatively short timescales, usually within 24 to 48 hours after the request.

When a stakeholder request is beyond the technical capabilities or available resources of the ASD, the group uses a contractor to provide the required services. Once the data is collected and ready for delivery, ASD delivers information directly to the requesting group. ASD are responsible for managing, vetting and coordinating contractors that provide RGB imagery and video, LiDAR, Ultraviolet (UV), IR and other types of sensor data collected by UAS contractors.

Enterprise Architecture (EA)

The Enterprise Architecture Department hold an enterprise view of the architecture of the information technology systems at the Sempra level meaning they are responsible for both SoCalGas and SDG&E architecture. They are responsible for defining the strategic direction of technologies with focus on information management.

2.1.2 Problem Statement

All design and construction tasks undertaken across SDG&E departments involve data collection. Currently, data is collected and stored by each individual department on their individual systems and as a result data sharing is limited. There is no central repository to store collected data and users can lose perspective of where data is held and may be unable to determine what area or location the data represents.

Implementation of a central repository will prevent duplication of effort, for example by preventing teams from inspecting or surveying areas that have already been recently inspected thus increasing operation and maintenance costs, improve decision making and result in overall cost savings for SDG&E. Data inconsistency is caused by maintaining information in parallel databases, transferring data from department to department, and not having a single point of responsibility for keeping it clean and up to date. Bringing all SDG&E data into a centralized system with a geospatial interface is essential to solving this problem.

Appendix A shows the current Infrastructure workflow and highlights the inefficient and ineffective steps in the process in red.

2.2 Vegetation Management Stakeholder Group

2.2.1 Responsibilities

A large part of Vegetation Management Team's duties concern powerline and pole safety. All state utilities are required by law to clear brush and debris from primary electrical power lines. There are around 460,000 trees spread over 8,700 miles across SDG&E's utility network.

Vegetation Management are responsible for adhering to these laws to:

- Prevent electrocution during a storm or accident
- Reduce the risk of fire
- Prevent unnecessary power outages

The pole brush program is a cyclical year-round effort to remove brush from the base of wood poles supporting power lines, that may cause fires. Poles with certain equipment such as fuses, switches, arrestors, and certain connectors are required to have a firebreak of ten feet or more in each direction. Pole brushing is the removal of all vegetation down to the bare mineral soil.

The program also includes clearing around transmission line structures. This fire prevention program is mandated by laws enforced by Cal Fire and California Public Resources Code Section 4292. SDG&E has a three-tiered program to assure that the poles remain in compliance.

There are three steps to clearing brush as part of routine maintenance:

Herbicides

From November through February vegetation around poles is cleared and treated with a herbicide to prevent re-growth.

Mechanical Brushing

From March through June, vegetation around subject poles that were not treated with herbicides are mechanically cleared.

Mechanical Re-Clearing

All poles that are not treated with herbicides are visited again during July through October for re-clearing.

The brush clearing program can be triggered for either of the following reasons:

- A routine maintenance cycle begins
- Off-cycle regulatory maintenance is required due to non-compliance

If a non-compliance is discovered, an assessment of the hazard it poses is made. If the risk can be mitigated safely in the next routine maintenance cycle, then it will be managed at that point. If it cannot, then an ad-hoc work order is created to conduct maintenance works immediately.

2.2.2 Problem Statement

Sending out staff to manually conduct inspections and auditing tasks is extremely time, labor and resource intensive and there are many associated safety and accessibility issues.

The current workflow undertaken involves a pre-inspection to identify overhead power lines and identify what work needs to be done, along with quality assurance auditing and inspection.

Vegetation Management would like to explore how the findings from the advanced data analytics can provide a snapshot of the current scenario and reduce the number of pre-inspections that need to be conducted. The findings would inform a maintenance schedule that is more focused and sends staff to conduct full inspections in areas of interest.

Another issue faced by Vegetation Management is the fact that they do not have access to any of the LiDAR and imagery collected by other departments because of the way in which this is currently collected and stored. A common theme among all stakeholders is the desire for a single centralized repository to promote data sharing between teams.

The system currently used by Vegetation Management to store their tree data is called Powerworks and is a standalone system, built on Inframap which is an iteration of the Environmental Systems Research Institute (ESRI) Geographic Information System (GIS) software. The tree geographic locations are not accurately represented in the system because of the way they are currently displayed; trees are "spread out" so the user can see them all instead of them being clumped together at their true locations. This can create confusion about where the trees are in reality. In an ideal world, this issue would be rectified, and all trees would have accurate GPS coordinates assigned to them, they would be stacked in clusters, but these clusters would transform into individual tree markers as the user zooms in.

Appendix B shows the current Vegetation Management workflow and highlights the inefficient and ineffective steps in the process in red.

2.3 Environmental Services Stakeholder Group

2.3.1 Responsibilities

The Environmental Services group are responsible for the permitting and licensing of new and replacement of gas and electric utility projects. Environmental Services is also responsible for ensuring that work on existing and proposed infrastructure occurs in compliance with all applicable permits and regulations. Part of that review entails avoiding and minimizing impacts to the environment. Environmental Services works with project initiators at the inception of a project to provide input and constraints data so that the proposed activity avoids or minimizes the impacts to the environment.

Environmental Services are consulted whenever a new construction project is initiated, this could be either a rebuild or modification to existing facilities or new construction of transmission or substation infrastructure capital projects. In the early stages of project development Environmental Services works with the project initiator to provide environmental constraints data to inform the design of the project and avoid or minimize impacts to the environment. Once the design is at 60% complete the Environmental team analyzes any potential environmental impact and provides input to determine the appropriate licensing and permitting requirements. The process involves various internal resources including Subject Matter Experts (SMEs) such as biologists, aquatic and cultural experts, as well as external environmental contractor resources.

Key Environmental Services responsibilities include:

- Conducting environmental inspections to review potential impact on aquatic resources, biological resources and cultural resources before permitting any construction work
- Maintenance, monitoring and restoration of environmental conditions post-construction

2.3.2 Problem Statement

Sending out personnel to carry out environmental inspections can be resource heavy and time consuming. Personnel may also face access issues such as the type of terrain, occurrence of hazardous plants and animals, and accessibility to pole and work locations. A recent environmental assessment took three members of environmental staff, four full eight-hour days to complete.

In an ideal scenario, Environmental Services would review existing data sets and fly an UAS or helicopter to collect data as a pre-condition to conducting an environmental inspection. The data would be analyzed as part of the initial desktop review and provide valuable information regarding vegetation species, land forms, existing disturbances, access routes, avoidance areas and surface information. This would allow the environmental inspection to be more focused and reduce the time spent walking from pole to pole to gather the types of information that could easily and quickly be collected by an UAS or helicopter.

The environmental inspection cannot be completely replaced by remote technology since an element of field work will always be required, for example field verification of aquatic resources requires field observations to make a determination. However, having up to date imagery can greatly improve inspection planning, reduce the number of hours the inspections take and free up resources to work on other tasks. The initial desktop review currently relies on Google Earth for imagery and this can sometimes be several years out of date which can result in an inaccurate perception of the environmental conditions.

In addition, the introduction of a mobile tool to collect and upload field notes and assessment details directly into the vendor system would greatly improve processes and efficiency. Duplication of effort would be eliminated since personnel would not need to type up their field notes on return to the office.

Currently, when data is collected by Environmental Services during a job walk, it is stored on an independent project drive and is not available for sharing and likewise Environmental Services does not have access to the data collected by any other group. Consequently, they have also expressed interest in the implementation of a single centralized repository to promote data sharing between teams.

Appendix C shows the current infrastructure workflow and highlights the inefficient and ineffective steps in the process in red.

3.0 Use Case Summary

Several stakeholder meetings and interviews took place and a variety of potential use cases were identified. A common theme discovered amongst all stakeholder groups was the lack of a centralized data repository to store and visualize the vast quantities of data collected by SDG&E. Currently all stakeholder groups collect, manage and maintain their own data, which is stored on a system unique to each department which makes data sharing amongst teams difficult.

Other use cases were selected that make use of advanced data analytics to improve and enhance stakeholder processes. A key focus was finding ways to reduce the number of laborious manual inspections that must be undertaken by the various stakeholder groups.

Throughout this report, the term ‘use case’ describes any case or scenario that was identified by the stakeholders to assist and provide efficiencies to their current workflow. A ‘test case’ is a use case that was selected, by the EPIC Team and stakeholders, for progression and demonstration by the vendors. This section describes all the use cases that were identified.

3.1 Infrastructure Use Cases

The Infrastructure stakeholder group focused on the idea of implementing a centralized repository for full data lifecycle management for design and construction projects. One of the largest construction programs that is currently active within SDG&E is the Fire Risk Mitigation (FiRM) Program and it provides a strong example of the data management obstacles SDG&E are faced with, due to the huge quantities of data that are collected each day.

The FiRM Program started in 2013 and includes replacing older overhead distribution line equipment with advanced technology and improving their system to adequately handle known weather conditions. As part of the utilities commitment to providing safe and reliable energy, they are proactively addressing fire risk by “hardening” the critical areas within their service area most at risk for wildfires. As part of this initiative, thousands of circuit miles of LiDAR, ortho imagery and oblique imagery data has been collected. Some of the data has been post processed and uploaded to the Procore file transfer site for distribution to involved parties or to the FiRM SDG&E File Transfer Protocol (FTP) site.

The centralized repository must have an appropriate role-based access control model in place. This should be used to restrict certain data access based on the user’s role and privileges, for example, transmission data, particularly bulk power transmission 230kV and 500kV should only be accessible by the Transmission Construction & Maintenance (TCM) and Transmission Engineering and Design (TED) Teams for reasons of cyber security.

The Infrastructure use cases describe how the vendor system can manage and maintain data throughout the full data lifecycle. The data lifecycle is shown in Figure 1.

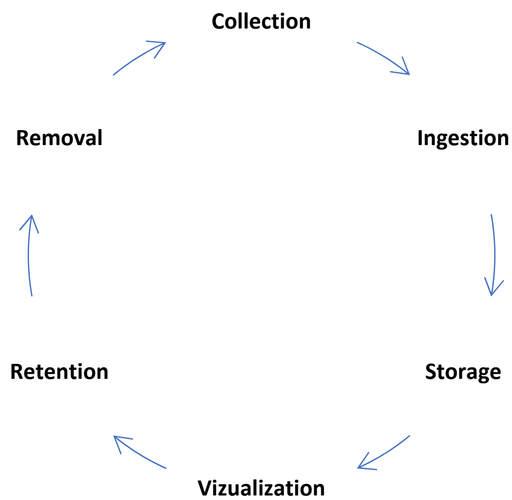

Figure 1: Data Lifecycle

3.1.1 Data Collection

Data can be collected for design and construction by UAS or helicopter or through traditional field data collection methods. Data collection is essential to all stakeholder groups and is the first step in the data lifecycle. For any of the documented use cases to commence, this use case must be executed.

UAS / Helicopter Data Collection

As part of the FiRM Program, an external vendor flies an UAS or helicopter to gather LiDAR and photogrammetry data from a given section of circuit. Photogrammetry data includes both orthorectified and oblique imagery.

This use case is triggered by the initiation of a project after the scoping of the project has been completed with internal stakeholders. The vast majority of the projects completed thus far includes the replacement of SDG&E's highest risk assets, small copper conductors and wood poles, in the highest risk fire locations.

Prior to flying the UAS or helicopter, appropriate permission must be sought from property owners in and around the flight path and other affected persons must be informed via the public outreach system.

Using a UAS or helicopter to collect LiDAR and photogrammetry data realizes the following benefits:

- Large quantities of data can be collected in a short timeframe
- Reduces the need for manual data collection inspections and patrols and consequently improves employee safety
- Ability to inspect difficult to reach and hazardous areas
- Resource, time and labor savings in comparison to field data collection methods

The overall flow of events for this use case includes the following steps:

1. Mission planning and risk assessment
2. Mobilization of UAS or helicopter
3. Collection of LiDAR and photogrammetry data

Throughout the FiRM Program, LiDAR and photogrammetry data will be collected throughout portions of the entire SDG&E service area.

Field Data Collection

Traditional field data collection, using 'feet on the ground', is an essential method for many SDG&E groups to take hand written field notes and photographs. The field data collection process could be significantly improved if a mobile device was used for collection.

Like most data collection requests within SDG&E, this use case is initiated by an engineering design contract which can either be a modification to an existing facility or new construction. The planning phase takes place where the data collection and resource requirements are identified before personnel go out and collect the data.

Within the FiRM Program, field data collection is known as a 'job walk' and includes representatives from the Design and Engineering Team, Land Services, Environmental Services, Construction, Surveying and Program Management. Before the job walk is undertaken, information about the circuit is gathered by the FiRM Program Team and includes data from the Engineering & Design Submittals, Corrective Maintenance Program (CMP) database, GIS, and photogrammetry. The Engineering & Design Consultant provides the following data in preparation for the job walk and are derivatives of the results of the PLS-CADD model that has imbedded in it the LiDAR and imagery data:

- Selected high risk poles in CSV format
- Map book including overview page, index page and pages for entire circuit
- ArcGIS shape file with pole locations and SanGIS parcel, owner, and assessor parcel number data included
- Google Earth KMZ file with pole locations and parcel data

Currently, field notes and photographs are taken as part of the job walk, and, in some cases, ecological field samples, such as soil and water samples, are also collected. Field notes are typed up and photographs are uploaded to each team's individual systems, when the representative returns to the office. Once in electronic format, the data stays with the team who has collected it which reduces data sharing opportunities.

If a mobile device is used for data collection, inefficiencies caused through duplication of effort are eliminated as the user does not have to travel back to the office to write up and upload the data. Generally, users are familiar with the functionality of mobile devices so formal training is not usually necessary for personnel.

The overall flow of events for this use case includes the following steps:

1. FiRM Team collect information about facilities
2. Job package is created by the GIS and/or Engineering & Design consultant
3. Job package is shared with FiRM Program Management Team, Land and Environmental
4. Job walk is planned out and collection requirements are identified
5. Job walk is conducted using vendor mobile app

3.1.2 Data Ingestion

Data can be ingested into the vendor system through various means. Like data collection, data ingestion is another essential step in the data lifecycle and must be executed before any of the other documented use cases can commence.

Common data types that are used within SDG&E include LiDAR, RGB oblique imagery, RGB nadir imagery, RGB video, GIS shape files, Powerworks shape files, PLS-CADD models, ultraviolet data, infrared data, field notes and other supporting documents (PDF, XLS, KMZ, DWG).

UAS / Helicopter Data Ingestion

After the data is collected, the data is processed and subject to a quality control procedure to check coverage, point density and imagery quality.

When the data has passed all quality control checks, it can be ingested directly into the vendor system for visualization and analysis. An intermediate file transfer step may need to be incorporated if the UAS / Helicopter contractor does not have direct access the vendor system.

The overall flow of events for this use case includes the following steps:

1. Data is processed and LiDAR rasters are produced
2. Quality control checks are undertaken
3. Data is uploaded into the vendor system

For further information about how LiDAR point clouds are converted into a raster, readers are directed to the University of Colorado, Earth Lab website.[2]

[2] University of Colorado. Earth Lab found at www.earthdatascience.org/courses/earth-analytics/lidar-raster-data-r/lidar-raster-data/

Field Data Ingestion

Data is collected in the field using a mobile device equipped with the vendor app. Once the data has been collected on the mobile device, it can be synced directly with the vendor system without the need to go back to the office to upload or type up information.

The vendor mobile data tool must have an offline capability that allows data collection when there is no internet connection. This allows collected data to automatically sync with the vendor system when connection is resumed.

Using a mobile device equipped with the vendor app for data ingestion realizes the following benefits:

- Loss of information risks are reduced since the information is uploaded directly into the vendor system, through the mobile device, in real-time
- Near instantaneous data transmission allows other users to make use of the data immediately
- Data is ingested directly into a single, centralized repository which promotes data sharing

The overall flow of events for this use case includes the following steps:

1. Collected data is subject to in field QC to check required data and imagery has been acquired
2. Data is uploaded directly into the vendor system from the mobile app

Batch Data Upload

There are some instances where batch data must be uploaded into the vendor system. Some examples include exploratory boring data or seismic refraction surveys. The data may be collected by an independent consultant or expert and provided to SDG&E in spreadsheet or PDF format. It is essential there is a function to ingest large quantities of data into the vendor system in one action.

Data that is uploaded must be shown at the correct location on the map and any associated metadata must also be ingested and displayed accordingly. The file in which the data is documented, for example the Exploratory Boring Report, should be associated to the specific coordinates of each boring location.

The overall flow of events for this use case includes the following steps:

1. Request for batch upload is received
2. Data is converted into a CSV file
3. Data is ingested into the vendor system in one action
4. Associated files are attached to the data points

There is potential to automate the batch upload process, if a need arose, for repetitive data ingestion on a weekly or monthly basis.

3.1.3 Data Storage

At this point, data has been collected and ingested into the vendor system. The data is stored in the vendor system which acts as a centralized repository for all data types. The vendor system must be scalable and able to handle a growing data set which could reach considerable quantities of data. In addition, a robust data backup and recovery protocol must be established to prevent data loss.

Information is one of SDG&E's most valuable assets so having a dependable system for the storage and management of the plethora of data is critical. Implementing a centralized repository will greatly improve access and retrieval of data for all users, it becomes easier for users to navigate and search for required information and improves data sharing between teams. Increased data sharing amongst teams results in resource, time and cost savings as data from areas that has been recently assessed can be used by other teams. This reduces the need for further field work. One of the key issues faced by SDG&E, is the fact that data is held on a variety of different systems that are not accessible to all.

The overall flow of events for this use case includes the following steps:

1. Data is ingested into the vendor system
2. Data is stored in a centralized repository

3. Users search against and retrieve data of interest via a text search or sort tool, or through a geospatial interface

3.1.4 Data Visualization

Once the data is retrieved from the centralized repository, it must be presented in a logical format to provide the best value to the user. This use case will explore how the vendor system can retrieve, display and present various data types. For the purposes of the demonstration, the provided data types include LiDAR, RGB oblique imagery, GIS shape files, Powerworks shape files, PLS-CADD models and other supporting documents (PDF, XLS, KMZ, DWG).

Data must be retrievable through a search function or by drawing a bounding box on the map. All data must be geospatially referenced and shown at the correct location on the map. Associated metadata, files and attributes must be displayed a when user drills down into each data point.

The overall flow of events for this use case includes the following steps:

1. Data is retrieved using a search function or bounding box
2. Data is displayed accordingly
3. Users drill down into a data point to view associated metadata, files and attributes

3.1.5 Data Retention

Data must be retained in the vendor system as specified in SDG&E's data retention policies. The data retention policy can vary between data type and data owner. Data relevant to the construction and maintenance of an asset must be retained for the life of the asset plus five years. SDG&E's entire overhead system (transmission and distribution) is comprised of approximately 263,000 overhead facilities, with over 73,000 poles for example that are 50 years old or older and have a long history of engineering & design and inspection data. This means there must be a mechanism that can feed in construction decommissioning dates and handle the volume of data efficiently. Consideration must be given to data that has multiple associations, the data must be retained for the life of its final association plus five years, even if the retention period for its historical associations has elapsed.

There may be a case to automatically assign a retention period to data on ingestion, this could be based on the role or department of the user ingesting the data, or on the type of data that is being ingested. It is important that this workflow can be manually overridden in the event the data type requires a different retention period than expected. To implement a mechanism such as this, SDG&E must develop a thorough retention policy for all their data types.

The overall flow of events for this use case includes the following steps:

1. Data retention period elapses
2. Data is flagged for removal

3.1.6 Data Removal

Once the data retention period elapses and the data has been automatically flagged for removal, data must be purged from the vendor system. Data removal can either be done automatically or the workflow can allow for human intervention to make the final purging decision. Depending on the quantities of data flagged for removal in a given period, human intervention may not be practical.

Data removal is important for the health of any centralized repository system. Holding data for longer than required slows down overall system performance, response time and users can be overwhelmed with the sheer quantity of out dated information. Having an effective purging mechanism opens memory or storage space for other uses.

It is important that data is disposed of effectively and securely according to industry standards. This prevents data or security breaches.

The overall flow of events for this use case includes the following steps:

1. Flagged data is permanently removed from the system
2. Data is disposed of according to industry standards

Appendix D shows the future Infrastructure workflow and highlights the process improvements and efficiency savings (in green) that could be made by introducing a centralized data repository.

3.2 Vegetation Management Use Cases

The Vegetation Management stakeholder group would like to explore how advanced analytical methods can supplement their inspection and auditing procedures. Sending out personnel to manually conduct inspections and auditing tasks is time and resource intensive and there is associated safety and accessibility issues as well as liability and insurance costs.

Their ideal future state is to regularly fly an Unmanned Aircraft System (UAS) or manned helicopter to collect up to date photogrammetry and LiDAR data, ingest this data into the vendor system, then use advanced data analytics to complement inspection and audit procedures. The findings would allow more focused maintenance schedules to be created resulting in a safer, more efficient process. Once the contractors are sent to conduct the maintenance works, details regarding the work carried out should be directly uploaded back into the vendor system using a mobile device whilst out in the field.

The use cases below describe the types of advanced analytics that could be conducted and how the results will benefit the Vegetation Management team. An assumption is made that the data has already been collected and ingested into the vendor system prior to the use cases beginning.

3.2.1 Identifying Hardware and Firebreaks

Some poles are fitted with hardware and due to the potential fire risk they can pose, poles must be cleared of brush for the safe delivery of energy. Pole brushing is the removal of all vegetation down to the bare mineral soil to act as a firebreak. The firebreak must have at least a 10-foot radius from the outer circumference of the pole or tower.

Typical non-exempt hardware found on poles includes universal fuses, open link fuses, enclosed cutouts with universal fuses, solid blade disconnects, in-line disconnects, lightning arresters, non-porcelain lightning arresters, hot tap clamps, split bolt connectors, fargo connectors, LM connectors, grasshopper air switches and transmission air switches.

Rules and regulations regarding equipment on poles and the need for firebreaks is outlined in Section 4292 of the California Public Resources Code:

“Any person that owns, controls, operates, or maintains any electrical transmission or distribution line upon any mountainous land, or forest-covered land, brush-covered land, or grass-covered land shall, during such times and in such areas as are determined to be necessary by the director or the agency which has primary responsibility for fire protection of such areas, maintain around and adjacent to any pole or tower which supports a switch, fuse, transformer, lightning arrester, line junction, or dead end or corner pole, a firebreak which consists of a clearing of not less than 10 feet in each direction from the outer circumference of such pole or tower.”

This use case explores how the vendor system can analyze LiDAR and photogrammetry data to:

- Identify specific hardware on poles
- Identify the presence of a firebreak
- Calculate the radius of the firebreak

The results from the analysis will allow Vegetation Management to quickly and effectively locate poles that are non-compliant and take appropriate remedial action. The findings can be used to inform the maintenace schedule which is more focused and reduces the need for pole to pole inspections. Maintenance personnel can be sent directly to non-compliant areas to take remedial action.

The following scenarios are classifed as being non-compliant:

- Any pole with equipment but no firebreak
- Any firebreak with a radius of less than 10 foot

Figure 2 shows various firebreak examples from a plan view at ground level as stipulated by the California Department of Forestry and Fire Protection.

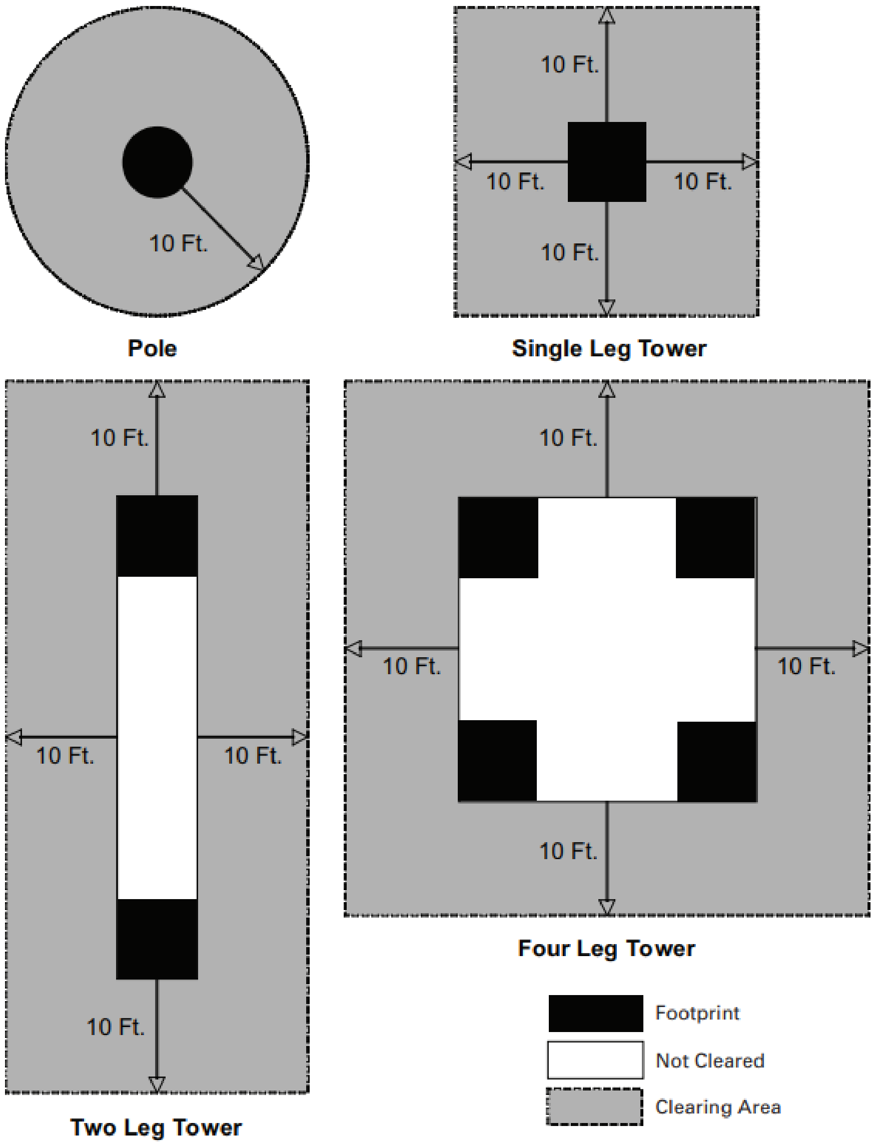

Figure 2: Firebreak Examples (Plan View at Ground Level)[3]

The overall flow of events for this use case includes the following steps:

1. Collected data set is subject to advanced analytics
2. Results are analyzed, and the following is established:
    a) Identification of hardware on poles

[3] California Department of Forestry and Fire Protection (2008). Power Line Fire Prevention Field Guide. Retrieved from: http://cdfdata.fire.ca.gov/pub/fireplan/fpupload/fppguidepdf126.pdf

   b) Identification of poles without hardware
   c) Identification of poles with firebreaks
   d) Identification of poles without firebreaks
   e) Calculate the radius of the firebreak
3. Informed maintenance schedule is created
4. Maintenance works take place
5. Field notes and maintenance details are uploaded directly into the vendor system through use of a mobile device

3.2.2 Identifying Tree Growth Patterns

Trees and vegetation grow at different rates depending on the surrounding environmental conditions. If the Vegetation Management Team had an idea of vegetation growth rates, maintenance works could be planned accordingly to prevent any non-compliances.

The vendor system must be capable of conducting advanced analytics on LiDAR and photogrammetry data to calculate the growth rates of specific vegetation types. Through comparison of historic versus current data, the growth or decline can be established. These rates will help prevent vegetation encroachment since maintenance works can be planned and conducted before it becomes non-compliant. If an area is found to be non-compliant, then contractors can be sent directly to the area to conduct corrective maintenance without the need to carry out pole to pole inspections.

Section 4293 of the California Public Resources Code outlines power line clearance requirements:

"Any person that owns, controls, operates, or maintains any electrical transmission or distribution line upon any mountainous land, or in forest-covered land, brush-covered land, or grass-covered land shall, during such times and in such areas as are determined to be necessary by the director or the agency which has primary responsibility for the fire protection of such areas, maintain a clearance of the respective distances which are specified in this section in all directions between all vegetation and all conductors which are carrying electric current:

a) For any line which is operating at 2,400 or more volts, but less than 72,000 volts, four feet.
b) For any line which is operating at 72,000 or more volts, but less than 110,000 volts, six feet.
c) For any line which is operating at 110,000 or more volts, 10 feet.

In every case, such distance shall be sufficiently great to furnish the required clearance at any position of the wire, or conductor when the adjacent air temperature is 120 degrees Fahrenheit, or less. Dead trees, old decadent or rotten trees, trees weakened by decay or disease and trees or portions thereof that are leaning toward the line which may contact the line from the side or may fall on the line shall be felled, cut, or trimmed so as to remove such hazard. The director of the agency which has primary responsibility for the fire protection of such areas may permit exceptions from the requirements of this section which are based upon the specific circumstances involved."

The overall flow of events for this use case includes the following steps:

1. Collected data set is subject to advanced analytics
2. Results are analyzed, and growth rates are calculated
3. Informed maintenance schedule is created
4. Maintenance works take place
5. Field notes and maintenance details are uploaded directly into the vendor system through use of a mobile device

3.2.3 Identifying Areas of Tree Health

Dead or dying trees can cause extreme fire danger in the SDG&E region as they allow wildfires to spread more rapidly in the already dry, hot, and drought-stricken environment. Consequently, Vegetation Management has an obligation to remove these trees and vegetation from around their assets as a preventative measure.

The vendor system must be capable of using advanced data analytics to identify areas of dead and dying vegetation. This can be done by inspecting changes in tree color, through analysis of infrared data or by other methods developed by the vendor.

Once the vendor system has identified these areas, maintenance contractors can be sent directly to the areas that require dead tree removal, eliminating the need for pole to pole inspections to check for dead vegetation. The overall fire risk is reduced because dead and dying trees can be identified and removed more quickly. Information about tree health can be shared with Environmental Planning for investigation.

Section 4292 and 4293 of the California Public Resources Code mentioned above, outlines power line hazard reduction and required clearances. In addition, Figure 3 provides a graphical representation of required vegetation removal around a pole. From the ground to 8 feet, all vegetation must be removed. From 8 feet to the conductors, all dead and dying vegetation must be removed.

The overall flow of events for this use case includes the following steps:

1. Collected data set is subject to advanced analytics
2. Results are analyzed, dead and dying trees are identified and flagged for removal
3. Informed maintenance schedule is created
4. Maintenance works take place
5. Field notes and maintenance details are uploaded directly into the vendor system through use of a mobile device

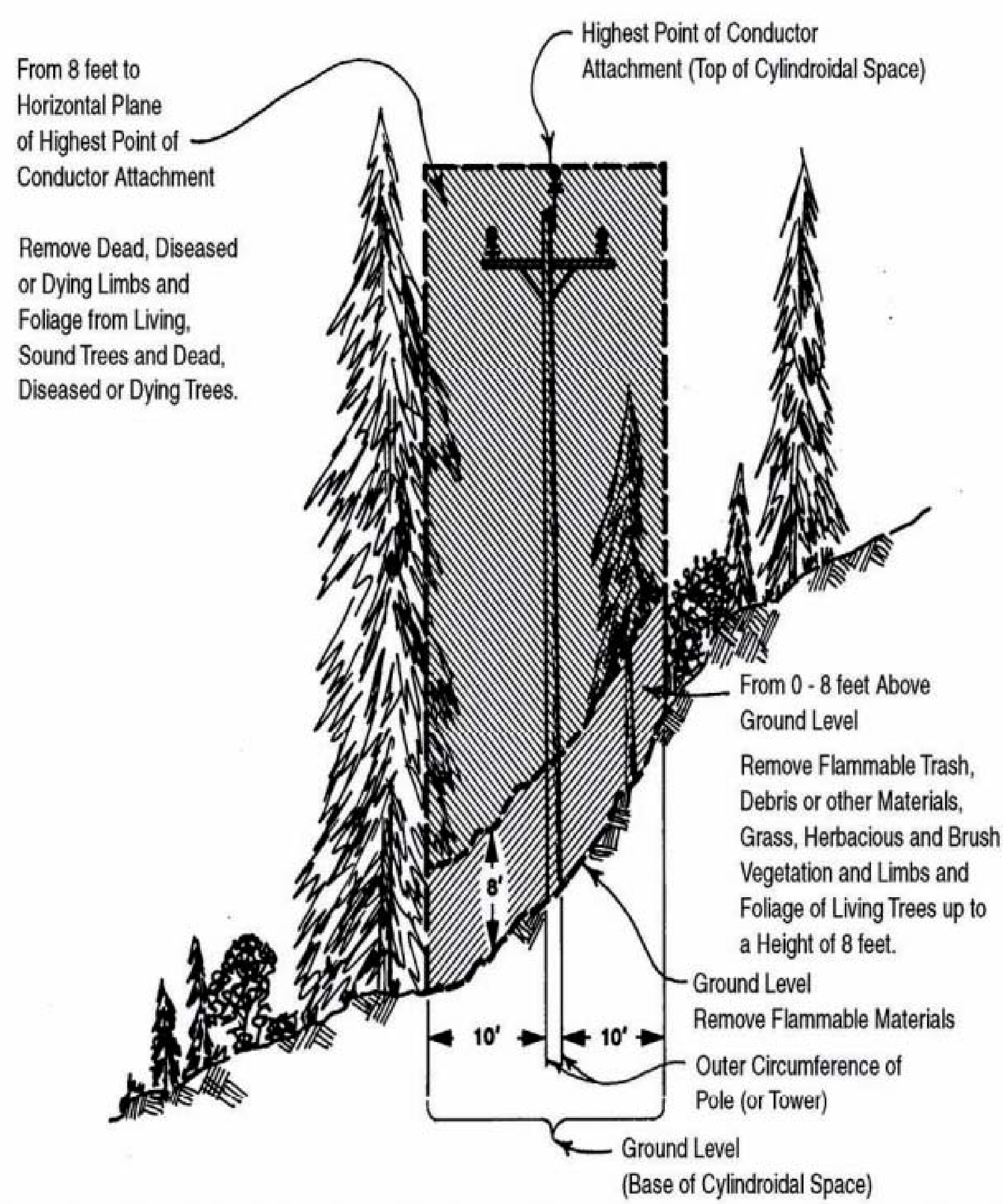

Figure 3: Firebreak Clearance Requirements Around Poles and Towers[4]

3.2.4 Identifying Changes in Pole Lean

Poles can begin to lean for various reasons such as pole damage and erosion issues at the pole base. Regulations state that poles must not lean more than 10 degrees from vertical. Any poles

[4] California Department of Forestry and Fire Protection (2008). Power Line Fire Prevention Field Guide. Retrieved from: http://cdfdata.fire.ca.gov/pub/fireplan/fpupload/fppguidepdf126.pdf

that lean by more than 10 degrees must be flagged so corrective action can be taken. Vegetation Management would like to explore how the vendor system can identify the degree of pole lean so preventative or corrective action can be taken without needing to conduct pole to pole inspections. They are also interested in how pole lean has changed over time and the underlying reasons for the pole lean.

This use case explores how the vendor system can analyze LiDAR and photogrammetry data to identify the current degree of pole lean, compare a historical and recent dataset to identify the degree of pole lean after a set time and identify the source of pole lean, for example, erosion at the base of the pole.

Vegetation Management would like the vendor system to adhere to the following criteria when displaying the pole lean findings:

- Pole lean of less than 7 degrees is acceptable and shown in green
- Pole lean of 7 to 9.9 degrees triggers a warning and is shown in yellow
- Pole lean of 10 or more degrees triggers an alert and is shown in red
- If a pole leans by more than 5 degrees in a year then this should trigger an alert:
  - If the pole lean has changed over time, the percentage lean should be shown in red
  - If the pole lean has not changed over time, 0% change should be shown in green

The overall flow of events for this use case includes the following steps:

1. Collected data set is subject to advanced analytics
2. Results are analyzed, and the following is established:
   a. Identification of the current degree of pole lean
   b. Identification of the degree of historical pole lean over a set time
   c. Identification of the source of the pole lean
3. Informed maintenance schedule is created
4. Maintenance works take place
5. Field notes and maintenance details are uploaded directly into the vendor system through use of a mobile device

3.2.5 Maintenance Audit

Vegetation Management conducts regular audits to check that maintenance works have been completed where and when they should have. This use case explores the idea of running advanced analytics on a random sample of data to check for both compliances and non-compliances. The findings would then be checked against any maintenance that has been completed in the field, by checking vendor system records and through means of a manual inspection. Details surrounding the audit could then be uploaded directly into the vendor system via a mobile device while out in the field.

The overall flow of events for this use case includes the following steps:

1. Dataset is subject to advanced analytics
2. Results are analyzed
3. Areas of auditing interest are identified
4. Check historical vendor system records for the random sample
5. Manual inspections are conducted to compare findings
6. If a non-compliance is located, corrective action is taken
7. Audit results are uploaded

Appendix E shows the future Vegetation Management workflow and highlights the process improvements and efficiency savings (in green) that could be made through advanced data analytics.

3.3 Environmental Services Use Cases

The Environmental Services stakeholder group, who primarily focus on the licensing and permitting of capital projects, would like to explore how implementing advanced data analytics can streamline their current processes and realize time and efficiency savings. One of the key issues faced by Environmental Services is the lack of updated aerial imagery necessary to conduct preliminary desktop environmental assessments and plan and organize in-field assessments for electric transmission and substation capital projects. Consequently, the desktop exercise may lead to inaccurate assumptions and the follow up in-field review can be extremely time and resource heavy.

The use cases below describe overall process improvements, the types of advanced analytics that could be conducted and how the results will benefit the Environmental Services team. An assumption is made that the data has already been collected and ingested into the vendor system prior to the use cases beginning.

3.3.1 Identification of Potential Pole Sites

The Environmental Services team plays an important role in licensing and permitting construction works, be it a new construction of electric transmission or substation infrastructure or modifications to existing facilities. If the vendor system could identify pole sites (existing and/or proposed) that lack access and are in or near sensitive environmental resources, this would help identify which pole sites require in-field review, allow fast identification of the appropriate Subject Matter Experts (SMEs) needed to attend the in-field review and reduce the overall amount of time taken to conduct the review. Members of the Environmental Project Permitting (EPP) Team and SMEs could be sent directly to the potential pole sites to conduct their environmental assessments and access could be arranged ahead of time for hard to reach areas that may not be accessible. A similar concept could be used to identify workspaces required to perform construction, such as stringing sites.

The overall flow of events for this use case includes the following steps:

1. Collected data set is subject to advanced analytics
2. Results are analyzed, potential pole and work sites are identified
3. A map book and list of potential pole or work sites is created
4. Personnel are sent directly to accessible areas of interest to conduct environmental assessment
5. Assessment details are uploaded into the vendor system through use of a mobile device
6. EPP with SME input make recommendations to minimize environmental impact
7. Design and construction begins

3.3.2 Identification of Water Bodies

The environmental conditions surrounding the existing and/or proposed pole is also important when considering a potential pole site and consequently it was decided that this use case should consider the distance of existing and/or proposed poles from water bodies. The vendor system should be able to calculate distances from certain environmental features and output the distances using red-yellow-green statuses depending on the criticality. The following criteria was defined by Environmental Services when considering the distance of a pole to a body of water:

- Green – water body is 100 feet or more away from the pole (acceptable)
- Yellow – water body is between 51 and 99 feet of the pole (warning)
- Red – water body is within 50 feet of the pole (critical)

The criteria above would help identify the existing and/or proposed poles near water bodies that need further review by an SME in the field. This information combined with the results for identifying potential pole or work sites will allow for a more efficient assessment process and better decision making when considering potential pole sites and their proximity to water.

The overall flow of events for this use case includes the following steps:

1. Collected data set is subject to advanced analytics
2. Results are analyzed, potential water bodies are identified
3. A map book and list of potential water bodies is created
4. Personnel are sent directly to accessible areas of interest to conduct environmental assessment
5. Assessment details are uploaded into the vendor system through use of a mobile device
6. EPP with SME input make recommendations to minimize environmental impact
7. Design and construction begins

3.3.3 Identification of Vegetation Community

Identifying the type of vegetation found where proposed construction work will take place is key to developing the environmental approach. Some vegetation communities are protected, they provide homes to other wildlife and are important for the overall diversity and preservation of the habitat.

Currently, identifying vegetation types is done manually by field crews on the ground and is a timely and arduous process. If general vegetation communities could be identified by conducting advanced analytics it would realize cost and time benefits and potentially locate and identify vegetation types that a desktop assessment may miss. Reducing or eliminating the need for manual in-field assessments, frees up resources to work on other assignments and prevents exposure to associated safety hazards.

This use case explores how the vendor system could identify or help confirm the vegetation community in an area of interest, which in turn will inform the construction approach that can be taken.

The overall flow of events for this use case includes the following steps:

1. Collected data set is subject to advanced analytics
2. Results are analyzed, and vegetation types are identified
3. A desktop analysis is performed with SMEs recommendations to minimize environmental impact and conduct an environmental field visit to specified pole locations if required
4. Assessment details are uploaded into the vendor system through use of a mobile device
5. Construction approach is developed considering vegetation types
6. Design begins

3.3.4 Identification of Birds' Nests in Vegetation

SDG&E is mandated by state and federal regulations to preserve and protect California's flora and fauna. Careful consideration must be given to assure the avoidance and minimization of impacts to nesting birds during construction projects. San Diego is home to several endangered and threatened bird species including the Coastal California Gnatcatcher and the Least Bell's Vireo[5]. It is extremely important these birds are protected to ensure their future survival.

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[5] U.S. Fish and Wildlife Service. Species by County Report. Retrieved from: https://ecos.fws.gov/ecp0/reports/species-by-current-range-county?fips=06073

Currently, Environmental Services work in collaboration with an independent SME to identify birds' nests during in-field environmental assessments. This is a difficult task, the nests can be buried deep within the vegetation, and there is a risk that birds' nests can go unidentified. Many nests are positioned on steep slopes, on top of the poles or other locations that may pose a safety risk to surveyors (when walking/hiking for surveys). The overall identification process is very inefficient and resource and time heavy.

If the vendor system could automatically identify birds' nests, then SMEs could conduct more focused assessments in these areas. The need for time consuming job walks to locate birds' nests may be reduced but on-the-ground survey would still often be required since drones cannot fly below the canopy to survey. In some cases, the vendor system may reduce safety risk by allowing surveyors to view nests in hazardous areas via drone, instead of walking/hiking on dangerous terrain.

This use case explores how the vendor system can use machine learning or advanced data analytics to identify birds' nests from within vegetation.

The overall flow of events for this use case includes the following steps:

1. Collected data set is subject to advanced analytics
2. Results are analyzed, and birds' nests are identified
3. Personnel are sent directly to areas of interest to conduct environmental assessment
4. Assessment details are uploaded into the vendor system through use of a mobile device
5. SMEs make recommendations to minimize environmental impact
6. Construction begins

3.3.5 Identification of Noxious Weeds and Invasive Species

Environmental Services would like to explore how the vendor system could identify specific noxious weeds and invasive species through machine learning or advanced data analytics. If automatic identification of these species was possible, with reduced need for laborious inspections to locate them, it would allow SDG&E to identify potential mitigation sites and manage and control required restoration areas more effectively and quickly, reduce the potential for harmful plant exposure to employees, and free up resources for other tasks.

Concerns over whether the technology, at this point, could identify all these species, were raised by Environmental Services and it was suggested that this technology would likely only be useful in identifying larger perennial species or some of the most common annual species. Most of the weeds treated by Environmental Services are annuals and need to be microscopically identified. However, moving forward this technology could be used to assign ranks for the likelihood of certain species to occur, likely preventative measures to prevent the spread of certain weeds or even the absence of weeds allowing Environmental Services to tailor weed introduction preventative measures.

The overall flow of events for this potential use case includes the following steps:

1. Collected data set is subject to advanced analytics
2. Results are analyzed, and plant species are identified
3. Personnel are sent directly to areas of interest to conduct environmental assessment
4. Assessment details are uploaded into the vendor system through use of a mobile device
5. SMEs make recommendations to comply with mitigation restoration requirements or identify potential mitigation/restoration (i.e. tamarisk removal) sites.
6. Mitigation planning or site restoration monitoring and reporting begins

3.3.6 Identification of Staging Yards

Staging yards are large, empty pieces of land that SDG&E use to house construction equipment and material when they are carrying out reconductoring or pole replacement works. This kind of work can happen anywhere along the line but ideally the poles must be within a 2-mile drivable distance from the staging yard. The staging yard should also be flat with no more than 5% slope, paved or bare ground and be at least 2 acres in size.

Currently, staging yards are identified as part of a pole to pole inspection. As already discussed, manual inspections are time consuming, resource heavy and have associated safety concerns. Environmental Services would like to explore how the vendor system can automatically identify potential staging yards according to the criteria outlined above. If there was a way to interface with land owner information this would produce huge efficiency benefits. The land owner could be approached by Land Services on identification of a potential staging yard to request permission and begin contractual procedures.

The overall flow of events for this use case includes the following steps:

1. Collected data set is subject to advanced analytics
2. Results are analyzed, and potential staging yards are identified
3. List of potential staging yards is created
4. Staging yard land owner is contacted to request permission to assess
5. Personnel are sent directly to potential staging yard to conduct environmental assessment
6. If suitable, land owner is contacted to request permission to set up staging yard
7. Contract between SDG&E and land owner is signed
8. Environmental Release is issued
9. Staging yard construction begins

3.3.7 Comparison of Pre- and Post-Construction Work Areas

The Environmental Post Construction team is responsible for the restoration of sensitive vegetation communities affected by construction activities once construction activities on a given project are completed. Vegetation within construction work areas are assessed prior to the initiation of construction activities and provide the basis for the required condition of the site at the completion of habitat restoration activities. The vegetation assessment consists of determining total native and non-native cover as well as identification of all plant species within the construction work area. Final success within the habitat restoration area is based on a percentage of the preconstruction native and non-native cover.

Using advanced data analytics, Environmental Services would like the vendor system to:

- Identify the vegetation types in the pre-construction and surrounding areas
- Calculate the percent cover of native and non-native species in the pre-construction and surrounding areas
- Identify the vegetation types in the post-construction and surrounding areas

- Calculate the percent cover of native and non-native species in the post-construction and surrounding areas
- Generate a pre- and post-construction comparison report

If successful, this could allow the Environmental Services team to compare vegetation types and native species before and after construction, and quickly and easily determine whether the preservation and restoration process was successful for that particular project. This kind of data is crucial for post-implementation reviews and lessons learned.

Again, concerns were raised regarding the practically of doing this and whether current technology has the capability to identify all species. Theoretically, you could fly a drone over the area at high resolution and identify some species, but plant identification requires microscopic inspection of flower parts and other anatomical features that can only be done by hand. Environmental Services also deal with multiple strata of vegetation which means this technology would need to record data through multiple layers of vegetation with significant detail to identify individual species and their total cover.

The overall flow of events for this potential use case includes the following steps:

1. Collected data set is subject to advanced analytics
2. Results are analyzed, and the following is established:
    a. Identification of vegetation type pre- vs post-construction
    b. Calculation of percent cover of native and non-native species pre- vs post-construction
3. Pre- and post-construction comparison report is automatically generated
4. Restoration and preservation success is determined
5. Data is used for post-implementation review and lessons learned

3.3.8 Pole Accessibility from Road

The current method of determining pole accessibility is by manually walking from pole to pole and taking hand written notes. On return to the office, these notes are transferred into electronic format and stored in the specific project drive. Table 2 is an example of the field notes that are taken when determining pole accessibility.

Location #	Environmental Field Comments
1	Existing road access to pole. On dirt pad.
2	No road access. Hike to top of ridge in Coastal Sage Scrub.
3	No road access. Suggest moving south towards dirt pad on bluff surrounded by Coastal Sage Scrub. May need to hike to install helo set.
4	Existing road access to pole. On dirt pad. In open grassy area. Surrounded by wetland in ravines below.
5	Existing road access to pole. On dirt pad. Existing erosion issues.
6	Existing road access to pole. On dirt pad. In open grassy area. Access via higher Orchard road to dirt two track. Avoid access coming from poles Z567890 and/or Z456789 since trucks would drive through a wetland. Frogs seen and heard in wetland.

Table 1: Example of Pole Accessibility Field Notes

The pole to pole field walks can encompass between 20 and 100 poles and take several days to complete. It would be very useful if the vendor system could use LiDAR and imagery data analysis to calculate the distance and elevation to the pole from the roadway. This would reduce the need for pole to pole walks and allow for better planning in terms of the duration of field visits, the equipment, vehicles and safety precautions required to access each pole. One idea for displaying the findings is to use digital terrain modelling to show the distance, profile and grade from the roadway to the pole. Figure 4, taken from Google Earth, gives an idea of how the findings could be presented in the vendor system.

Figure 4: Option for Displaying Pole Accessibility Information

The findings from this analysis will inform Environmental Services of the distance and elevation of a pole from a roadway. This information will assist in the planning of job walks and constructability to access a pole; access may require construction of a new road, foot travel or overland travel and act as a screening tool to determine which poles are of interest to SMEs and require further inspection, making the overall process more effective and efficient.

The overall flow of events for this use case includes the following steps:

1. Collected data set is subject to advanced analytics
2. Results are analyzed, and the following is established:
    a. Distance from roadway to pole
    b. Elevation from roadway to pole
3. Findings inform planning of pole to pole inspection walk
4. Personnel are sent directly to areas of interest to conduct field assessment
5. SME recommendations are provided to project manager/engineer

3.3.9 Capture of Pole Accessibility Field Notes

As mentioned above, the current method of capturing pole accessibility notes is through means of a physical pole to pole inspection and taking handwritten notes and photographs. These notes are then typed up when the employee returns to the office.

Environmental Services would like to explore the idea of using a mobile tool, such as a tablet or other smart device to capture field notes and photographs while in the field. The mobile tool must be intuitive and easy to use and have the capability to automatically upload the field notes into the vendor system in real-time. Additionally, if the mobile tool had the capability to allow dictation using voice recognition software, statistics show that productivity may be increased by up to three times in comparison to typing. All collected data must be time and date stamped and the tool must be GPS enabled to provide geolocational information about where the data was collected. In addition, it is essential the mobile tool has an offline capability that allows data collection when there is no internet connection. Collected data must automatically sync with the vendor system when the connection is resumed.

Introducing a mobile tool for in field data collection will realize the following benefits:

- On the whole, users are familiar with using mobile devices so there will not be a heavy training burden
- Duplication of effort is reduced since the staff member will no longer have to type up their notes on return to the office
- Data can be uploaded into the vendor system in real-time resulting in near instantaneous transmission and decreasing idle times for staff waiting for the information
- Reducing idle times increases productivity in other areas and results in cost and resource savings
- Less time, effort and money are spent transporting personnel to and from the office to conduct inspections and write up notes
- Loss of information and data transcription errors are reduced; mobile platforms allow forms to be completed in the field and uploaded immediately
- Dropdown lists and other constrained values can be incorporated into the mobile tool to ensure consistent data collection

The overall flow of events for this use case includes the following steps:

1. Personnel are sent directly to areas of interest to conduct inspection walk
2. Field notes and photographs are collected using a mobile device
3. Data is saved and uploaded directly into vendor system
4. Data is made available to those who need it

Appendix F shows the future Environmental Services workflow and highlights the process improvements and efficiency savings (in green) that could be made through advanced data analytics.

4.0 Test Case Summary

After the potential use cases had been identified and documented, a decision was made by the EPIC Project Team, SDG&E stakeholders and vendors as to which test cases would be progressed considering the dataset provided and time and budget constraints of the project.

Once the team had determined which were possible, meetings took place between the vendors and stakeholder groups to achieve their buy in and listen to the vendor proposals. The stakeholder groups were satisfied with what the vendors proposed and gave them to go ahead to begin their platform design and development. The key purpose of this effort was to provide a pre-commercial demonstration of the vendor tools capability to assist stakeholders in the decision-making process of adopting a commercial tool in the future.

A 'test case' is a use case that was selected, by the EPIC Team and stakeholders, for progression and demonstration by the vendors. This section outlines which test cases were chosen for development and demonstration and gives an overview of the dataset that each vendor was supplied with by SDG&E for the purposes of the project.

Appendix G, the Vendor / Stakeholder Use Case Matrix, shows the use cases that were selected for progression and highlights the use cases that are common between the stakeholder groups.

4.1 Test Cases - Vendor A

The following test cases were selected for progression by the EPIC Project Team, SDG&E stakeholders and Vendor A. A full description of each can be found in Section 3.0, the Use Case Summary section.

4.1.1 Infrastructure

- Data Ingestion

4.1.2 Vegetation Management

- Identifying Changes in Pole Lean
- Maintenance Audit

4.1.3 Environmental

- Identification of Water Bodies
- Pole Accessibility from Road

4.2 Test Cases - Vendor B

The following test cases were selected for progression by the EPIC Project Team, SDG&E stakeholders and Vendor B. A full description of each can be found in Section 3.0, the Use Case Summary section.

4.2.1 Infrastructure

- Data Ingestion
- Data Storage
- Data Visualization
- Data Retention
- Data Removal

4.2.2 Vegetation Management

- Identifying Tree Growth Patterns

- Identifying Areas of Tree Health
- Identifying Changes in Pole Lean

4.2.3 Environmental

- Pole Accessibility from Road
- Capture of Pole Accessibility Field Notes

4.3 Baseline Data Set

The vendors were supplied with a baseline data set that included all the necessary files to demonstrate the selected test cases. A section of circuit was selected for the demonstration, made up of a 1.25-mile segment of SDG&E distribution circuit including 30 poles.

This segment was selected because the program had already collected data on this area during previous rounds of EPIC. Furthermore, the EPIC team was able to exploit LiDAR and imagery data had been collected as part of the FiRM Program back in September 2017 and more recently in early 2018.

The baseline data set included the following files:

- PLS-CADD models of design and as-built conditions, including Drawing Exchange Format (DXF) exports of the line and pole facilities, LiDAR cloud and stringing charts
- GIS electric distribution poles and vegetation data in database and shape file formats
- Log ASCII Standard (LAS) file of LiDAR point cloud collected in September 2017 and again in early 2018
- Documentation including SDG&E standards, pole identification lists, construction plans, Keyhole Markup language Zipped files (KMZs) and various reports
- RGB imagery collected during flight mission for PLS-CADD design
- Additional RGB imagery from other circuits for advanced data analytics totaling approximately 3000 photos
- High resolution oblique and nadir imagery collected in September 2017
- UAS close range oblique imagery and UAS pole-centric imagery for select poles

- Classified LAS file for entire test segment
- Environmental geodatabase, shapefiles and layers

5.0 Vendor Tool Demonstration System Design, Development and Setup

5.1 Vendor A – Vendor A Tool

5.1.1 Vendor A Tool System Summary

Utilities need to manage assets while simultaneously optimizing costs, improving safety, and ensuring reliability and customer satisfaction. With a large portion of budgets tied up in fixed costs, remote sensing applications are being looked to as a way to loosen the margin squeeze. Imagery from satellites, fixed-wing aircrafts, and UAS can provide a tremendous amount of data. But having data is not enough, the data needs to be transformed into information to answer specific questions and provide actionable intelligence.

Vendor A has developed a utility asset management platform called Vendor A Tool to help automate, scale, and optimize asset management operations to meet business challenges. Vendor A Tool can manage, process, and analyze geospatial imagery, apply deep learning, and deliver actionable intelligence. Figure 5 gives a pictorial view of the Vendor A Tool overall workflow.

Figure 5: Vendor A Tool Workflow Overview

5.1.2 Vendor A Tool Feature Summary

Manage Big Data

As utility companies capture and consume more remotely sensed data, establishing a centralized data management system is core to the foundation of their business. Users throughout the organization need quick access to the right data to make informed decisions.

Vendor A Tool fully utilizes Vendor A's core competency in processing, storing, discovery, and exploitation of geospatial data at scale and is able to ingest imagery, video, LiDAR and other forms of remotely sensed data to analyze utility transmission and distribution infrastructure. With Vendor A Tool, users in the field or in an operations/data center can quickly locate critical intelligence with advanced discovery and filtering capabilities so they can make informed decisions with a high degree of confidence.

Process and Analyze Data

Vendor A Tool is architected to deploy any number of analytics, including image classification, multi and hyperspectral analysis, and LiDAR feature extraction. These capabilities are brought together in Vendor A Tool in the form of utility-specific workflows, allowing a utility of any size to take advantage of all of the power of Vendor A's remote sensing analytics.

Deep Learning Technology

Vendor A Tool exploits advanced deep learning technology focused on extracting insights from remotely sensed data. Beyond standard libraries designed to detect common anomalies on transmission and distribution infrastructure, new classifiers can be developed with specific data collected by the utility and deployed within Vendor A Tool to provide tailored inspection analytics. These analytics can be automated to run on data ingest in real-time or used interactively by analysts to review and improve the deep learning models.

5.1.3 Platform Compatibility

Vendor A Tool has been tested using Windows 8.1 or higher. Supported browsers currently include:

- Chrome 67 or higher
- Firefox 60.0 or higher

The LiDAR Viewer requires a modern graphics card such as NVivida or AMD, which are manufactured from 2012 or later.

5.1.4 Deployment Options

Vendor A Tool can be implemented in a secure hosted environment or on premise, with deployment options dependent on preferred utility metrics such as circuit-miles covered, number of assets analyzed and imagery data size managed.

For on premise deployment, One Server class machine or EC2 instance with the following system requirements is recommended:

1 Server with GPU:

- 4 core 2.4 GHz Intel Xeon® CPUs
- 64 GB RAM
- NVidia GPU with 8GB or more of video memory

However, given the stage in early development, it is recommended SDG&E consider a cloud-based solution. This will provide the most flexibility and allow the system to scale up or down based on the amount of data collected, processed, and ingested. There are no known size limitations on file types at this time.

5.2 Vendor B – Vendor B Tool

5.2.1 Vendor B Tool System Summary

Vendor B's platform is called Vendor B Tool and it is used to provide solutions for both Transmission and Distribution utility networks. These solutions provide users with a view of the data that supports their day-to-day tasks and strategic objectives. Vendor B Tool has been designed to enable faster decision making by providing a central location to view critical asset and infrastructure details. Users can navigate the 'virtual grid', explore 3D models, perform virtual inspections, and initiate action.

Vendor B Tool delivers high-resolution imagery and LiDAR-derived business intelligence and data is immediately accessible and actionable for ongoing daily utility operations. Vendor B Tool is a secure, cloud-based, geospatial solution requiring minimal IT configuration and provides access to high-resolution ortho and oblique imagery, video of SDG&E assets and vegetation encroachment calculation and visualization. In addition to imagery, Vendor B Tool provides visualization for any feature-coded LiDAR data. Tools to virtually inspect assets using high definition imagery are supplied and this data is stored to create a digital library of the health of assets, which can be tracked over time.

The following points outline the key data hosting and visualization benefits supplied by Vendor B Tool:

- Secure, hosted web-delivery with 'Google Earth' like navigation
- High resolution orthophoto and oblique imagery
- Ability to ingest data from various sources
- 3-D classified and colorized LiDAR fused with ortho imagery
- Raster and vector data such as centerlines, canopy segments, and right-of-way boundaries

5.2.2 Vendor B Tool Interface Overview

This section describes the basic functionality of the Vendor B Tool interface and the overall look and feel of the platform.

The Explorer tab, found on the ribbon shown in Figure 6, contains buttons that are most commonly used.

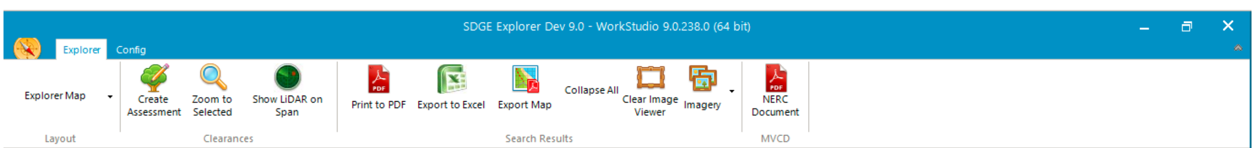


Figure 6: Vendor B Tool 'Explorer' Tab

A brief description of their functionality can be found below:

- **Layout** – changes layout view
- **Create Assesment** – creates a job in the client software
- **Zoom to Selected** – zooms to item selected on map
- **Show LiDAR on Span** – downloads LiDAR file for the span selected on the map
- **Print to PDF** – Prints selected items
- **Export to Excel** – export tabular data for items selected or queried

- **Clear Image Viewer** – clears out all images that have been added to the viewer
- **Imagery** – shows available imagery for selected items
- **NERC Document** – PDF of the North American Electric Reliability Corporation (NERC) standards for reference

The Config tab gives users options to change their layout preferences and download the LiDAR viewer, as shown in Figure 7:

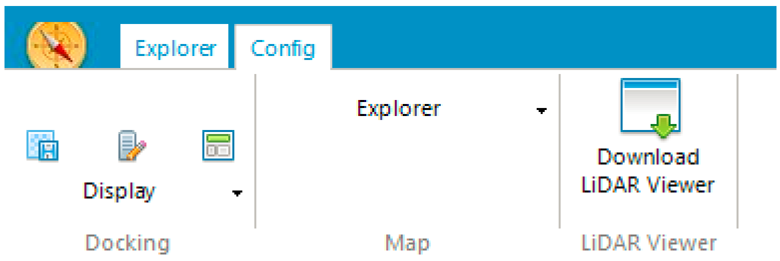


Figure 7: Vendor B Tool 'Config' Tab

The map controls are shown in Figure 8 with a brief explanation of their functionality.

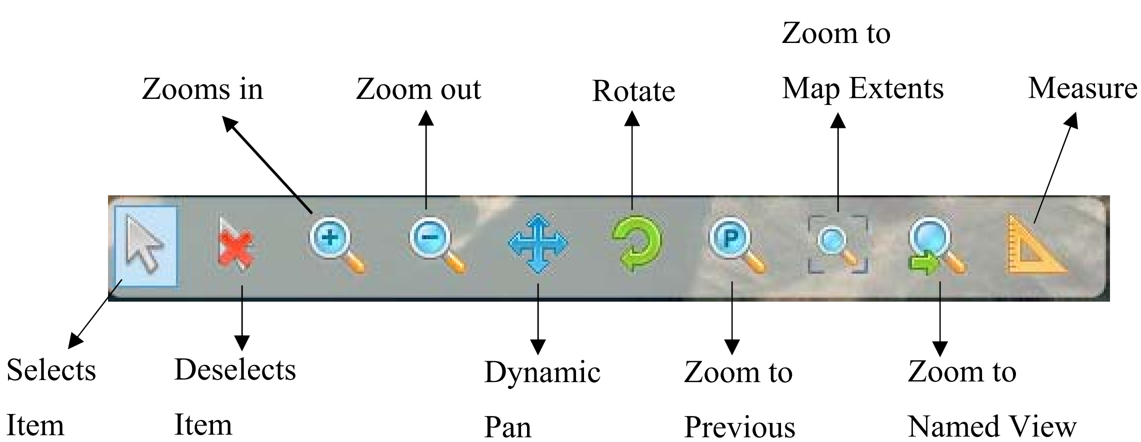


Figure 8: Vendor B Tool Map Controls

The sidebar, shown in Figure 9, shows the various map layer options that were ingested into the demo system. Note that; when the light bulb icon is yellow, the layer is switched on.

The blue light bulb means the layer will be active at a select map zoom.

When the blue light bulb is struck out with a red line, the layer is switched off.

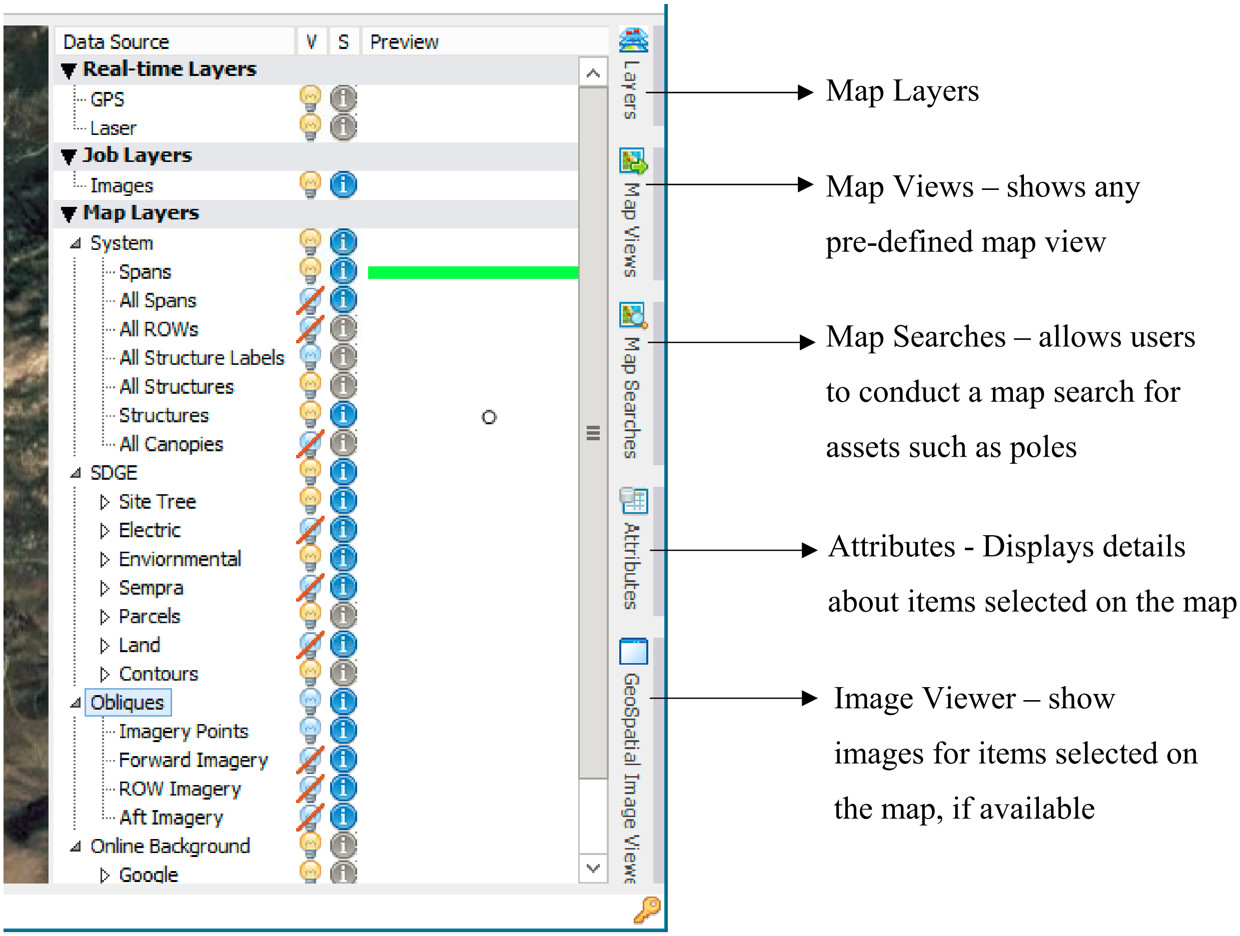


Figure 9: Vendor B Tool Map Layers Sidebar

Work searches are pre-configured queries against the Vendor B Tool database. A built-in tool, known as the Data Source Modeler, is used to join separate tables in the database together to get the results the user is looking for. Pole lean for example, the standard structure table is taken, which contains the name, location etc., and joined to the detailed table for structures where the pole lean information is located. The information is presented to the users and the degree of pole lean is established.

When fresh data comes in for ingestion, Vendor B has a data loading process that takes the data from the Production team and loads it into the database. If there are multiple surveys (i.e. different flights), the user can set the filter to only show the results for that survey.

Figure 10 shows how the work searches sidebar is configured to allow the user to search and filter against the data analytics results.

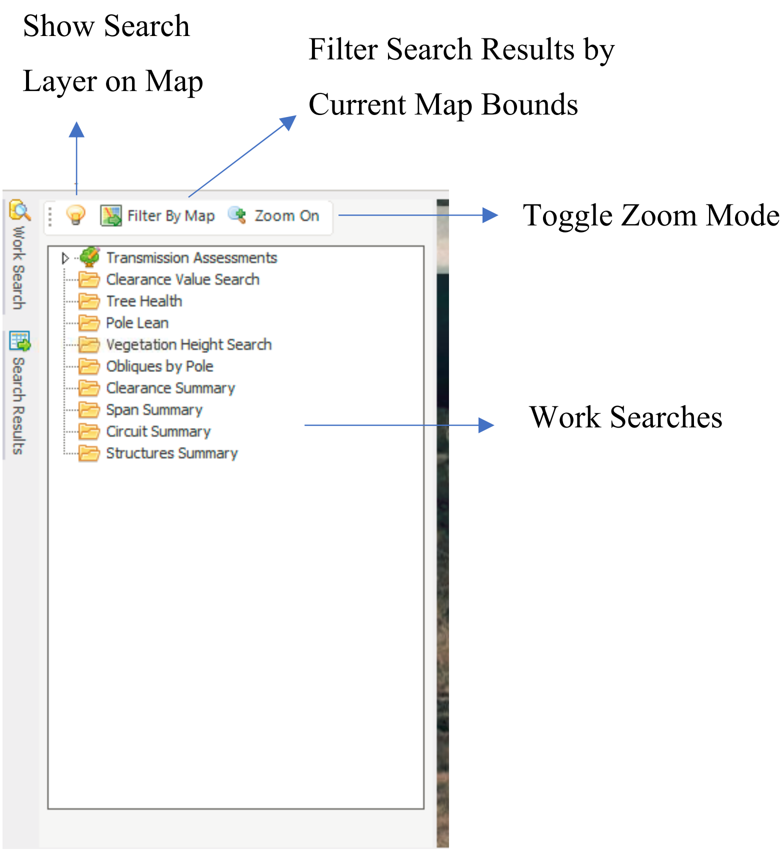


Figure 10: Vendor B Tool Work Searches Sidebar

5.2.3 Vendor B Tool System Requirements

Table 2 below highlights key system requirements. Each requirement is either already included as part of base functionality or is planned to be added in future iterations. Requirements that have been designated ‘customer enhancement’ require full development and build out on a per customer basis and will vary dependent on needs.

System Requirement	**Base Functionality**	**Planned Functionality**	**Customer Enhancement**
Data Storage Type: Digital pictures (varying resolution)	X		

System Requirement	**Base Functionality**	**Planned Functionality**	**Customer Enhancement**
Data Storage Type: Video (varying resolution)		X	
Data Storage Type: Infrared images	X		
Data Storage Type: LIDAR data	X		
Data Storage Type: Partial discharge		X	
Data Storage Type: Audio			X
Data Storage Type: Temperature	X		
Data Storage Type: Magnetic			X
Data Storage Type: Humidity	X		
Data Consumption: UAS	X		
Data Consumption: ROV	X		
Data Consumption: Cellular/smart phone	X		
Data Consumption: Internet/Cloud	X		
Data Consumption: Other			
Data Correlation/Association and Search	X		
Data Display/Map Interface	X		
Image Cropping		X	
Analytics Capabilities: Ability to recognize and detect physical change in the characteristics of the asset based on the pictures/video	X		
Analytics Capabilities: Ability to recognize and detect physical change in the characteristics of the asset base on the infrared data	X		

System Requirement	Base Functionality	Planned Functionality	Customer Enhancement
Analytics Capabilities: Ability to recognize and detect physical change in the characteristics of the asset based on the Lidar data	X		
Analytics Capabilities: Ability to recognize and detect physical change in the characteristics of the asset based on the partial discharge data			X
Analytics Capabilities: Ability to recognize and detect physical change in the characteristics of the asset based on the audio data			X
Analytics Capabilities: Ability to recognize and detect physical change in the characteristics of the asset based on the temperature data			X
Analytics Capabilities: Ability to recognize and detect physical change in the characteristics of the asset based on the magnetic data			X
Analytics Capabilities: Ability to recognize and detect physical change in the characteristics of the asset based on the humidity data			X
Analytics Capabilities: Ability to recognize and detect any other physical change in the characteristics of any other data			X

System Requirement	Base Functionality	Planned Functionality	Customer Enhancement
Analytics Capabilities: Library of existing electric utility assets you have already trained	X		
Analytics Capabilities: Ability to trigger events, via integration or otherwise based on detected change	X		

Table 2: Vendor B Tool System Requirements

5.2.4 Vendor B Tool System Architecture

5.2.4.1 Hardware

Application Server. The application server is a physical box that the WorkStudio Server and Vendor B Tool application is installed on.

Database Server. The database can reside on the same physical box as the application server or it can be held on a separate physical box.

Storage Platform. The storage platform set up can vary depending on the amount of data that will be stored. In some cases, an object storage server may be required in addition to store video, imagery, LiDAR data, magnetic information, thermo imagery and audio.

5.2.4.2 Software

5.2.4.2.1 Operating System

The Operating System specification is outlined in Table 3:

	Work Studio Server	Work Studio Client	Work Studio Client	Work Studio InfoCenter
Device	Server (virtual or physical)	Tablet PC	Desktop PC	Server (virtual or physical)
CPU	Intel® Xeon®	Intel® i3/i5/i7®	Intel® i3/i5/i7®	Intel® Xeon®
Processor Speed	2 GHz or higher	2 GHz or higher	2 GHz or higher	2 GHz or higher
Minimum Memory	8 GB	4 GB	4 GB	4 GB
Free HDD Space	200 GB	80 GB	80 GB	80 GB
Operating System	Microsoft® Windows® - Server 2008 R2 - Server 2012	Microsoft® - Windows® 7 - Windows® 8 - Windows® 10	Microsoft® - Windows® 7 - Windows® 8 - Windows® 10	Microsoft® Windows® - Server 2008 R2 - Server 2012
Network	1,000 MB/sec	100 MB/sec WLAN	100 MB/sec	1,000 MB/sec
Suggested Hardware Options		GPS Camera 4G/LTE AirCard		
Other Software	SQL 2012/ 2012R2/2014/2016 Oracle database 11g/12c Oracle Client	Firefox IE8 or higher Chrome		SAP Crystal Reports Microsoft® IIS 7.5+ .NET 4.0 Oracle Client

Table 3: Vendor B Tool Operating System Specification

5.2.4.2.2 Communications

Vendor B uses a proprietary binary TCP/IP format known as Data Objects to communicate between the client application and the server application. The payload is encrypted via SSL using standard TLS based encryption.

5.2.4.2.3 Integration Protocols and Data Formats

Regarding integrations, Vendor B have a JSON API that can be utilized via http. They also have an internal binary proprietary TCP/IP API that has a .NET toolkit developed to interact with. Vendor B have a tool built into our product known as the DSM (Data Source Modeler) which is used to extract and transform data into a view that can be presented to the end user.

5.2.4.2.4 Availability and Reliability

Vendor B’s secure Data Center is operational 24x7x365. Vendor B hosts many utility systems and ensures this data is reliable and accessible at all times. Customers covered under an annual maintenance agreement also have access to the Vendor B Support center, which is open Monday through Friday 7am – 6pm Central Time.

5.2.4.2.5 Performance

Database. Depending on the data that is housed in the database, the database can range from a few kilobytes in size up to 100 GB.

Performance. Can vary based on what action is currently being taken. Most operations will take less than a second to respond. The usual benchmark that is followed by Vendor B is that a user should never have to wait more than 5 seconds for an operation to take place.

Concurrency. Vendor B has carried out testing with up to 100 concurrent users within the system. It can vary greatly as to what kind of concurrency would be expected for most actions.

5.2.4.2.6 Security

Vendor B adheres to the NIST 800-53 Standard for Storage & Handling of Information and Data. This standard exceeds the requirements of NERC CIP. Vendor B also provides a written Information Security Plan based on client requirements and industry best practices.

6.0 Vendor Test System Demonstration Approach, Results and Recommendations

6.1 Vendor A Test Case Results

6.1.1 Infrastructure

As part of the Infrastructure test case, Vendor A demonstrated how the Vendor A Tool could ingest various data types, which are outlined below:

- **File Formats**
  - JPEG
  - LAS/LAZ
  - Vector/shape files
- **Deep Learning** - while these are the formats required for the Vendor A Tool deep learning engine, almost any data type can be converted to one of the supported deep learning formats before processing occurs.
  - TIFF
  - JPEG
  - ENVI
  - LAS/LAZ
- **Vegetation Encroachment**
  - LAS
  - PLS-CADD exported DXF files

6.1.1.1 Data Ingestion – Uploading and Ingesting Pole Data

6.1.1.1.1 Approach

As part of the baseline dataset, SDG&E provided an as-built pole list which provided the exact locations of the poles contained in the circuit, as well as their ID, location, and elevation. The Vendor A Team created a CSV file for demonstration purposes to be used as the vessel for ingestion.

In addition to pole information, two items were added to the CSV file: the map coordinate system (EPSG) and a “Pole Must be Brushed” column. The EPSG value is required to determine the exact map coordinates based on the X, Y, and Z values. The “Pole Must Be Brushed” column contains a zero or one, depending on whether the pole is expected to be brushed. The EPSG Geodetic Parameter Dataset is a collection of definitions of coordinate reference systems and coordinate transformations which may be global, regional, national or local in application.[6] Table 4 shows an example CSV file containing the aforementioned pole data:

Type	**Structure No.**	**Station (ft)**	**X Easting (ft)**	**Y Northing (ft)**	**Centerline Z Elevation (ft)**	**TIN Z Elevation (ft)**	**Ahead Span (ft)**	**Line Angle (deg)**	**Pole Must be Brushed**
ESPG	2230								
Pole	P370070	647.106	6365541	1907218	1105.83	1105.83	172.42	6.1283	0
Pole	P139204	819.526	6365616	1907373	1108.30	1108.30	62.886	5.1828	0

Table 4: Pole Data CSV Example

Once the CSV file was created, the pole data was successfully ingested into the Vendor A Tool. The following analytics were automatically performed when the pole information was uploaded:

- Determination of the pole accessibility from the closest road
- Identification of the proximity of water to a pole
- The database is updated and an association between images and poles is created
- The database is updated and an association between LiDAR data and poles is created

6.1.1.2 Data Ingestion – Uploading and Ingesting LiDAR Data

6.1.1.2.1 Approach

LiDAR data can be uploaded to the system as LAS or LAZ files. If the file header contains an EPSG map coordinate code, the upload process automatically detects the coordinate system. If the file header does not contain the EPSG code, users must specify the EPSG coordinate system

[6] International Association of Oil and Gas Producers. About the EPSG Dataset. Retrieved from: http://www.epsg.org/

during the upload process. As with any map-based system, if no code or the wrong EPSG code is provided, the data and results will not use the correct coordinate system.

When a LiDAR dataset contains multiple tiles (LAS/LAZ files) all the LAS/LAZ files should be uploaded in one step.

If multiple LiDAR collects exist for a specific area; for example, the same area collected months apart, the datasets must be uploaded in two different steps.

The following actions were automatically performed once the LiDAR dataset is uploaded:

- Metadata is extracted, including collection date and EPSG code (if available)
- The database is updated and an association to poles that fall within the extents of the LiDAR dataset is created
- The pole lean is computed and a calculation of the change in lean is made if previous measurements are available
- Poles requiring a firebreak maintenance audit are identified and vegetation encroachments within the 10-foot protected area around each pole are detected

6.1.1.3 Data Ingestion – Upload and Ingest UAV Images

6.1.1.3.1 Approach

UAV JPEG images were uploaded to the system along with the pole data, either as one step or separately. One or more JPEG files could be uploaded at a time.

The following actions are automatically performed once the pole information was uploaded:

- exif metadata is extracted, including the GPS location and date of collection
- The database is updated, and an association is created between images and poles. When users click on a pole, the map view for the primary (closest) image is displayed

6.1.1.4 Data Ingestion – Optional Upload Settings

6.1.1.4.1 Approach

During the upload process, the collection date is determined by the exif metadata tag for imagery and the LAS header for LiDAR data. If the exif or header details are not available, the collection date defaults to the date of the upload. Users can override this value by specifying a collection date.

During the upload process, users can specify a retention period that dictates when the system automatically purges the data from the system. If no value is provided, the image will be retained indefinitely.

6.1.1.5 Data Ingestion – Add /Edit /Remove Attachments to or from a Pole

6.1.1.5.1 Approach

In addition to associating imagery and LiDAR data with poles, users could attach other file types to assets within the Vendor A Tool. To attach a file to a specific pole, the user should click on a pin in the map, or select an image from the catalog view, to access the Image Viewer. Within the Asset Details section, a document could be attached by clicking the upload icon. A file browser window appeared which was used to navigate to the desired file.

Once a document had been associated with the pole, the attachment could be accessed by clicking on the filename and downloading the file to a local desktop. Users are able to make edits on their local system and reattach the updated document to the system by clicking the upload icon next to the filename. Multiple files could be associated to an individual pole. Attachments could also be removed by clicking the remove button. Figure 11 shows the attachments menu.

Figure 11: Attachments

6.1.1.6 Data Ingestion - Use Batch Processing to Add Reports to Specific Georeferenced Locations

6.1.1.6.1 Approach

SDG&E stakeholders, particularly the Infrastructure group, require the ability to create a batch process to upload Seismic Refraction Surveys and Exploratory Boring reports to an area, to share across the organization. Since each report contains a different format and metadata, Vendor A defined a CSV format for each report type according to the format specified in the sample report as shown in Table 5 below:

Exploratory Boring Locations

Type	ID	Lat	Lon	Ground Elevation	Exploration Date	Depth	Units
Boring	B-1	33.29963	-116.943	1529	3/7/2018	19.5	Qc
Boring	B-2	33.316	-116.939	2321	3/7/2018	19.5	RS/grwx

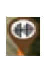
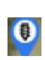
Seismic Refraction Surveys

Type	ID	Lat1	Lon1	Lat2	Lon2
seismicrefractionsurvey	SL-1	33.3195	-116.937	33.31979	-116.936
seismicrefractionsurvey	SL-2	33.3157	-116.939	33.31603	-116.939

Table 5: Boring and Seismic CSV Format Examples

During the upload process, users can choose settings such as the collection date, owner, and retention policy. The collection date will default to the date on the file; however, users can specify a collection date. If a retention policy is not specified, the file will remain in the system indefinitely.

Once the data was uploaded, the documents appeared as small markers in the map view:

- Seismic Survey: 
- Exploratory Boring Report: 

If the attachment is in a format that the browser can display, for example a PDF, users are able to click on the marker and view the file within the Vendor A Tool. If the web browser does not support the file format of the attachment, users were prompted to download the file. Once downloaded, the required software application could be launched to view the data.

6.1.1.7 Data Ingestion – Overall Results

The Vendor A Tool successfully demonstrated the ability to create a central repository for imagery, LiDAR, and georeferenced files. This coupled with on-ingest analytics provided all users with a single source of the most current data and actionable insights to make informed and timely decisions.

Furthermore, the system demonstrated the ability to use vector shapefiles and public domain digital elevation models (DEM) to generate actionable results.

Users of the system can quickly locate details about the overall health of assets or filter results and conditions based on specific needs such as vegetation, environment, or inspections.

Analytic results can be exported to a CSV file and used to update existing GIS asset information such as vegetation encroachment, missing avian covers and other analytic conditions.

6.1.1.8 Vendor A Recommendations

The following functional recommendations should be considered to maximize results in an operational environment:

- Formalize user and group requirements for access roles, security protocols, and common data retention policies among stakeholders.
- Create pre-built workflows to provide targeted results based on user-defined roles. For example, determine asset health according to a specific functional group's needs such as groups and organizational functions leaning poles, vegetation encroachment, etc.

- Develop dashboards to easily diagnose analytics results and filter relevant data by functional group. With increased data volume and archived information, it will be critical to provide streamlined access to insights generated by the system.

6.1.1.9 Conclusions

The Vendor A Tool is a viable and robust solution for the transmission and distribution asset management workflow. The underlying technology is designed to scale up and outward, which will allow the system to grow to meet storage and processing needs as usage expands.

Using data provided, the imagery and results of the analytics developed as a part of the proof of concept were successfully ingested and catalogued into Vendor A's data management system using an automated process. Results were automatically categorized, and visual indicators were provided to alert users to specific areas of concern. This test case successfully demonstrated that users across the organization can quickly and easily access data to make informed decisions regarding the state of the infrastructure, how to mitigate vegetation risks, or when to respond to environmental issues. Several implementation recommendations were provided to anticipate the use of the system in an operational environment.

While this test case demonstrated a lightweight client for viewing imagery, layers, and results, the scope did not target system integration. As next steps are explored for operationalizing the system, the Vendor A Tool has been architected so that it can be integrated solely as a backend solution.

6.1.1.10 Export Results for Downstream System Integration with GIS

Although not one of the official documented use cases, information technology (IT) stakeholders expressed interest in having access to the Vendor A Tool analytic results to include in their GIS system of record. The desired outcome was to link the two systems using Open Geospatial Consortium (OGC) data access standards. However, in the short term, the team requested the ability to export the results to a CSV file that can be easily scripted to update their GIS system. Additional stakeholder groups expressed an interest in using the results for planning purposes.

6.1.1.10.1 Approach

Working with stakeholders, conditions such as leaning poles and severity were defined, as outlined in the test cases above. Users could filter by specific conditions and any combination of severities, such as the severity (angle) of pole lean. The CSV format delivered as a part of the export was tailored according to each condition, for example:

- **All**: All details for each condition
- **Pole Lean** contains: Pole ID, Date, Pole Longitude, Pole Latitude, Pole Elevation, Severity, Information, Lean Change, Pole Angle Degrees 1, Measurement Date -1, Pole Angle Degrees 2, and Measurement Date 2
- **Pole Access** details: Pole ID, Date, Pole Longitude, Pole Latitude, Pole Elevation, Access Severity, Information, Nearest Road Point Longitude, Nearest Road Point Latitude, Elevation gain (m), Distance to Road (m), Terrain Max Slope (rise/run), Terrain Min Slope (rise/run), Elevation Climb (m), and Elevation Difference (m)
- **Avian Covers** details: Pole ID, Date, Pole Longitude, Pole Latitude, Pole Elevation, Avian Cover Severity, and Information
- **Encroachment** details: Date, Encroachment Severity, Information Encroachment Distance, Encroachment Longitude, and Encroachment Latitude
- **Water Proximity** details: Pole ID, Date, Pole Longitude, Pole Latitude, Pole Elevation, Water Proximity Severity, Information, Distance to Water (m), Nearest Water Point Longitude, and Nearest Water Point Latitude
- **Brushings** details: Pole ID, Date, Pole Longitude, Pole Latitude, Pole Elevation, Information, Brushing Severity, Brushing Date, Brushing Center Longitude, Brushing Center Latitude, Brushing Min Height (m), Brushing Max Height (m), Brushing Points 10 feet, Brushing Points 20 feet, Brushing Date 2, Brushing Center Longitude 2, Brushing Center Latitude 2, Brushing Min Height (m) 2, Brushing Max Height (m) 2, Brushing Points 10 feet 2, and Brushing Points 20 feet 2

The GIS team indicated that their short-term solution is to create script files to consume various portions of these outputs and to update their GIS records via a batch process. The output formats were created to provide stakeholder information derived from the analytics (such as terrain information) to aid in planning. Vendor A stated they can easily adjust the CSV output formats to meet stakeholder needs.

6.1.1.10.2 Results

Vendor A successfully proved a simple form of integration could be done from the Vendor A Tool. Further studies are recommended to understand operational requirements and expand output results to include bounding boxes boundaries, polyline coordinates, and volume metrics.

6.1.1.10.3 Vendor A Recommendations

The CSV outputs in this test case were simple examples to show the concept of moving data through the system. Recommendations include:

- Conduct study to understand operational requirements for downstream systems; e.g., GIS.
- Develop APIs to share asset records on demand or as scheduled processes.
- Integrate Map layers to share spatial information.

6.1.1.10.4 Conclusions

While a lightweight integration methodology was demonstrated, one or more common OGC data access standards, including Web Map Services (WMS) and Web Feature Services (WFS) can be used to share information between systems. Moreover, APIs must be created to populate and maintain links between the GIS records and the Vendor A Tool.

In the past, the Vendor A have demonstrated a simple case of using OGC layers to connect to ArcGIS which should be expanded to include sharing asset records and additional map layers. The Vendor A Tool and on-ingest analytics can be used in its current form or it could be deployed as a backend data store with the analytics exposed through the ArcGIS toolkit.

6.1.2 Vegetation Management

6.1.2.1 Identifying Changes in Pole Lean

6.1.2.1.1 Approach

The pole location was provided as part of the as-built pole information and when the LiDAR classified point cloud data was uploaded to the Vendor A Tool, the on-ingest analytics calculated the pole angle through a series of steps. To calculate the pole lean, all points associated with the pole were extracted, while other points were removed.

The height of the pole was identified by subtracting the vertical position of the top-most point from the bottom-most point. Once the height was calculated, points that lie between 1 meter from the bottom and 2 meters from the top were removed. This left only the middle segment of the pole which is a more reflective sampling of the pole angle. A Random Sample Consensus (RANSAC) algorithm was used to calculate the best fit line, which reflects the pole angle. The angle of the pole defines the severity and is outlined in Table 6:

Indicator	**Condition**	**Tilt / Lean**
Green	Normal	< 7 degrees
Yellow	Warning	7 – 9.9 degrees
Red	Alert	>= 10 degrees

Table 6: Pole Lean Conditions

If multiple point cloud datasets existed for a particular pole, the pole angle difference was calculated between the current dataset and the closest previous dataset in time. To account for normal variations between collections, the pole angle difference was highlighted in red when the change was greater than 2 degrees. If the difference was equal to or less than 2 degrees, the value was highlighted in green. In situations where the pole lean had been remedied, the pole angle difference reflected a negative value and is highlighted in green. Figure 12 shows a sample of the leaning pole details.

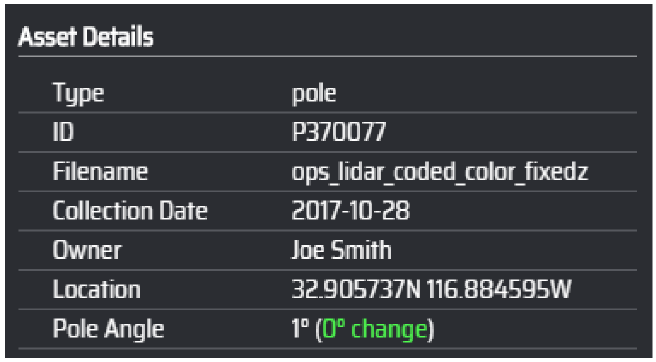


Figure 12: Leaning Pole Details

6.1.2.1.2 Results

Vendor A found that the sample dataset used for this demonstration did not contain any poles meeting the criteria for warnings or alerts. To verify analytic results, a pole was created by duplicating an existing pole, placing it in a new location, and rotating the points to create a significant lean extending over two collection timelines.

The pole accessibility results were quickly located by conducting a search and filter query. Users can filter against the pole lean proximity condition and the desired severity. The pin colors in the map indicated the severity of the pole lean. Green specified that the angle is normal, yellow indicated warnings, and red alerted the user to when a pole is leaning more than 10 degrees. Figure 13 shows the search and filter functionality when considering pole lean.

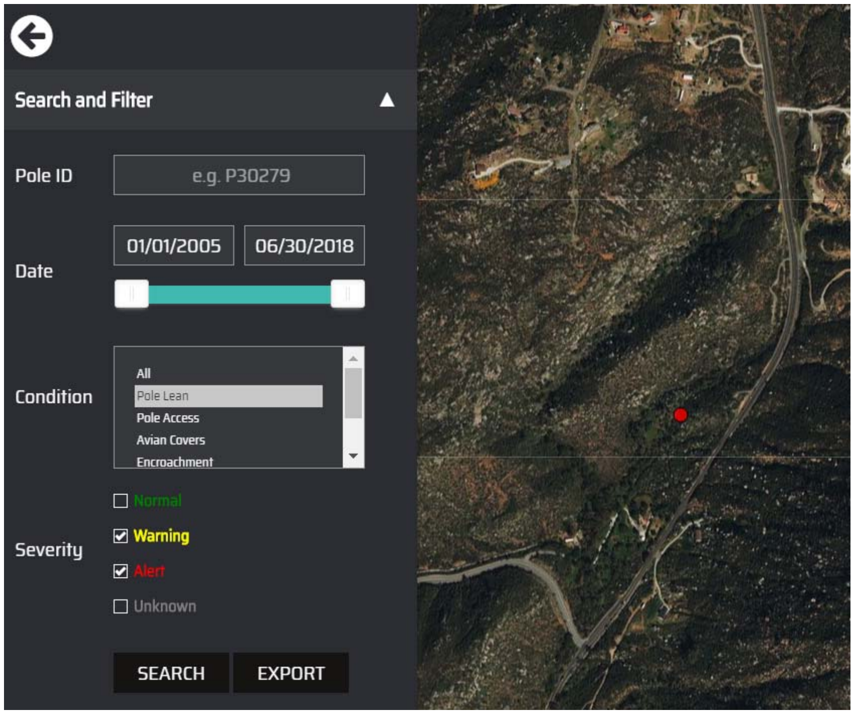


Figure 13: Search and Filter by Pole Lean

When point cloud results were viewed, the camera is pointed toward the selected pole. A grey vertical axis was displayed to help visualize the pole's current angle, as show in Figure 14.

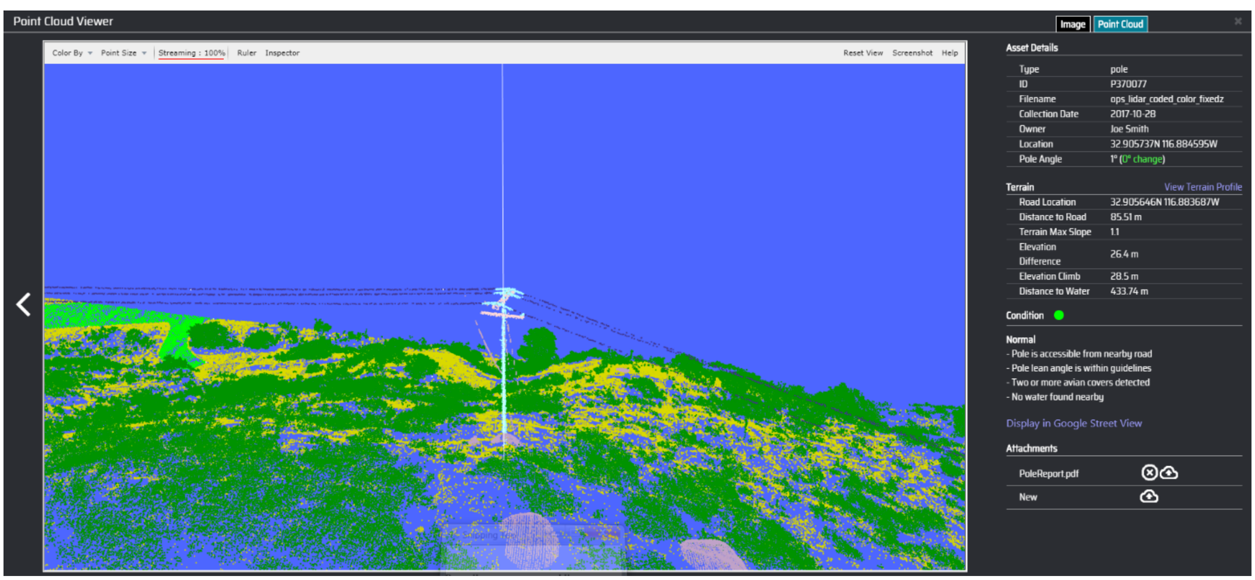


Figure 14: Point Cloud Viewer

Using the Point Cloud Viewer application, users were able take a simulated orbital flight around the pole. In addition, the results could be manually viewed using a mouse to navigate through the point cloud. Users could also choose to view the pole angle from the road by clicking the Display in Google Street View link.

Using as-built pole information and LiDAR point cloud data, algorithms were successfully developed by Vendor A to calculate pole angles. Results were confirmed by viewing the calculated RANSAC best fit values for each of the 37 poles included in the demonstration. Figure 15 illustrates two examples.

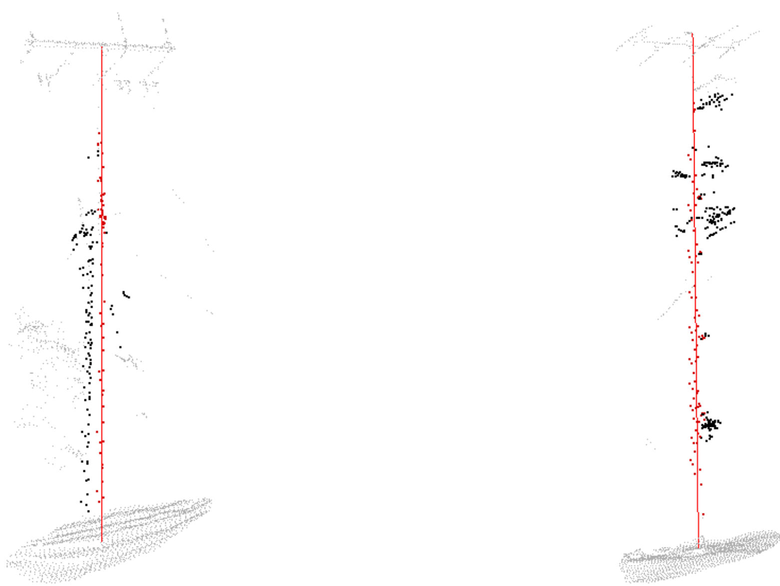


Figure 15: Calculated Best Fit Line

Grey dots represent the points excluded from the calculation. Red and black dots represent the points used by the algorithm to calculate the best fit. The red line represents the calculated best fit line. In both cases, Vendor A stated that the algorithm performed as expected.

While most results were successful, there were four cases where the calculated best fit line used the outside radius points on opposite sides of the pole instead of the center points. In the most extreme case, the pole lean was calculated at a higher value of 7.3 degrees versus the correct value of 3.1 degrees, as shown in Figure 16. Vendor A confirmed that this rare case could be addressed by applying additional filtration methods and by improving the best fit scoring mechanisms used by the algorithm.

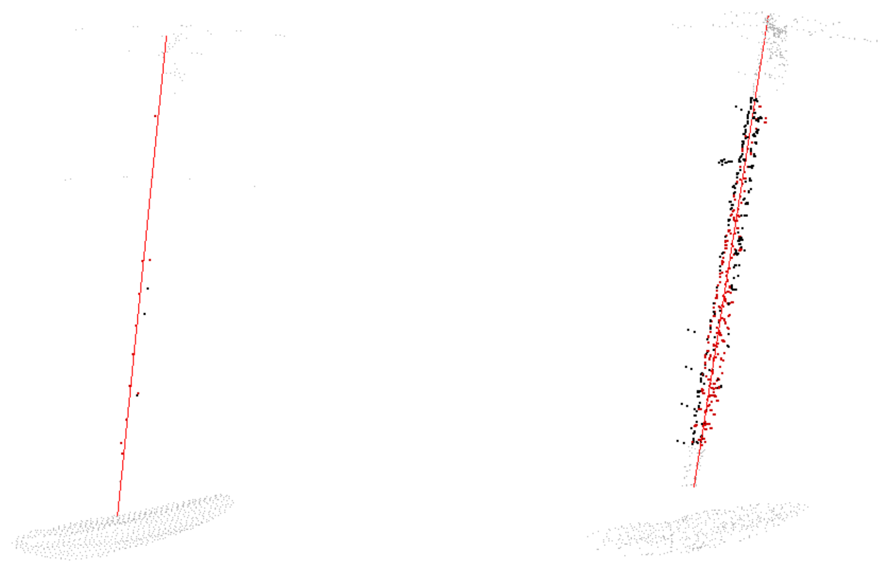


Figure 16: Outside Radius Points Used to Calculate Best Fit

To evaluate the algorithm's accuracy, the calculated best fit line for each pole was visually compared to the expected center line. Vendor A found the algorithm demonstrated 93% of the poles were measured accurately. The accuracy results are displayed in Table 7:

	LiDAR Dataset 1 (34 poles)	**LiDAR Dataset 2 (38 poles)**
Best fit line correctly identified	31	36
Best fit line slightly misaligned	2	2
Best fit line outside of pole	1	0
Accuracy	91.2%	94.7%

Table 7: Accuracy Results

6.1.2.1.3 Vendor A Recommendations

Recommendations for further development concerning the pole lean test case include:

- Use deep learning to identify pole locations in an unclassified LiDAR dataset. While SDG&E provided a classified point cloud and subsequent as-built location details, removing the need to classify point clouds could reduce costs and improve turnaround times.
- Apply additional filtering options to calculate best fit and refine best fit scoring options in pole lean algorithms, which will improve results.
- Expand the difference calculation by comparing the latest angle to the previous one to calculate the rate of change for the pole over time.
- Add a visual indicator to reflect where 90° is expected, relative to the calculated pole angle.
- Integrate the Vendor A Tool with existing work order systems, to verify work has been performed to remediate a leaning pole and to identify poles to include in a maintenance audit.
- Explore with stakeholders if the pole lean algorithm should be modified from reporting degrees of lean to percent change relative to the pole's height.
- Use an RGB per-point LAS file to help users and provide more meaningful visualization to users.
- Integrate the pole lean results. An RGB LAS file can be generated by collecting LiDAR and imagery simultaneously with the organization's work management systems to verify work has been performed to remediate a leaning pole. An RGB LAS file can be generated by collecting LiDAR and imagery simultaneously.

6.1.2.1.4 Conclusions

This test case proved that the pole angle can be automatically calculated using LiDAR data and the pole location. The overall accuracy indicates the analytics can provide actionable insights for poles at risk. In addition to calculating the current pole angle, the test case was expanded to show the difference from one collect to the next. As this workflow is operationalized, the analytics should be extended to incorporate all available time series values to create a predictive rate of change.

6.1.2.2 Maintenance Audit

6.1.2.2.1 Approach

To determine if firebreak maintenance is required, pole locations and brush status were provided to Vendor A in the as-built pole information. When the LiDAR classified point clouds were uploaded to the Vendor A Tool, the on-ingest analytics evaluated if a firebreak existed on the required poles.

Using the classified point cloud, the algorithm defined a 10-foot cylinder around the base of the pole. Using standard American Society for Photogrammetry and Remote Sensing (ASPRS) feature codes for high, medium, and low vegetation, the algorithm queried the LiDAR holdings for points in that area that were feature-coded as vegetation. Vegetation points found within the cylinder were colored red to indicate encroachment as shown in Figure 17.

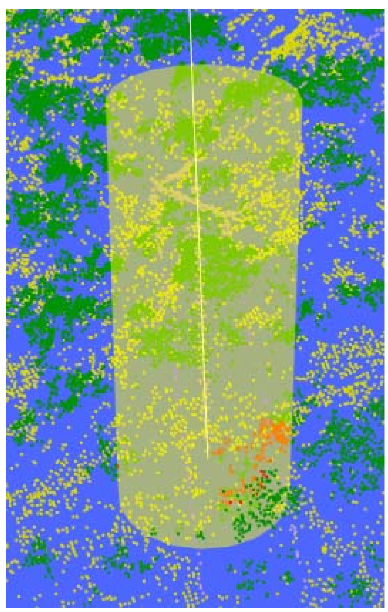


Figure 17: Vegetation Points Detected within a Firebreak

If vegetation is found within the defined firebreak, the severity is set accordingly. Table 8 shows the severity conditions:

Indicator	Condition	Firebreak
Green	Normal	Required / No Vegetation Detected
Red	Alert	Required / Vegetation Detected

Table 8: Firebreak Severity Matrix

6.1.2.2.2 Results

The pole brushing results were quickly located by conducting a search and filter query. Users can filter against the pole brushing condition and the desired severity as shown in Figure 19. The pin color on the map indicated the severity. Green indicated that the pole had been brushed and is normal. Red alerted the user to when vegetation exists within a pole firebreak that should have been brushed.

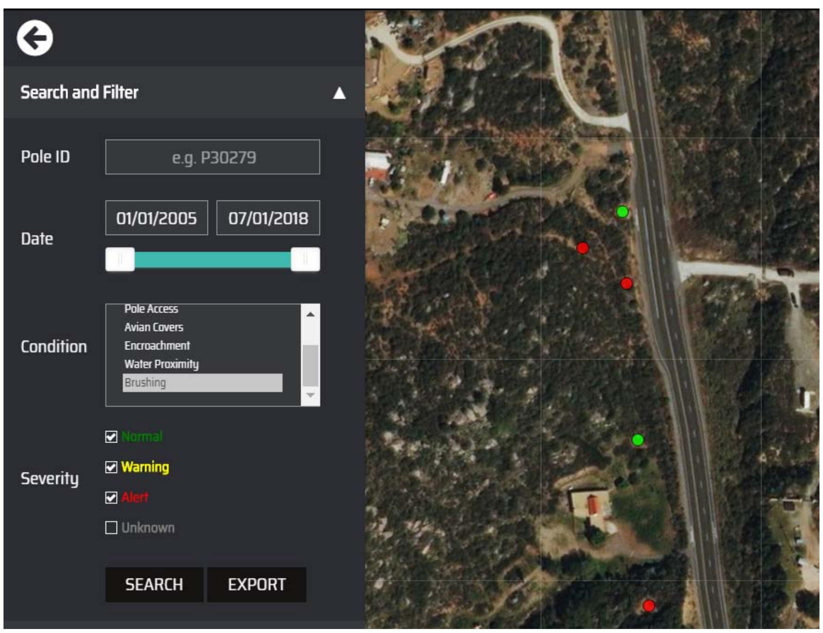


Figure 18: Search and Filter for Firebreak Maintenance Audits

When viewing point cloud results, the camera is pointed toward the selected pole. A yellow cylinder was placed around the pole to help visualize the vegetation within the firebreak as displayed in Figure 20.

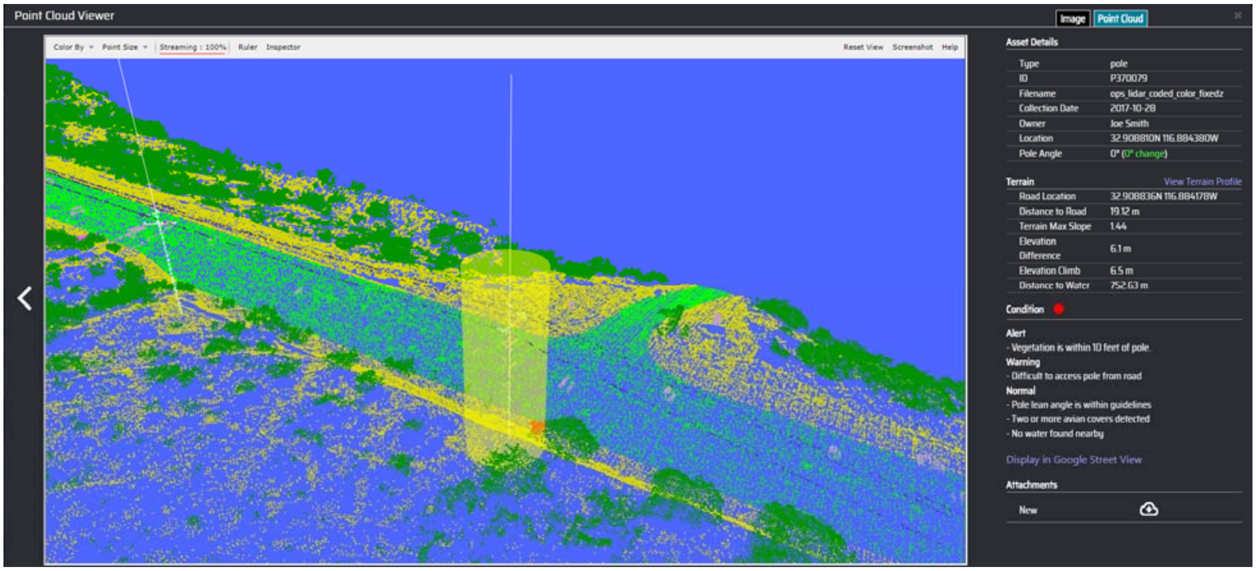


Figure 19: Vegetation within Firebreak

Using the Point Cloud Viewer application, users were able take a simulated orbital flight around the pole. In addition, the results could be manually viewed using a mouse to navigate through the point cloud. Users could also choose to view available imagery in addition to point cloud data, as well as clicking the link to view the pole from the road using Google Street View.

Using classified LiDAR point cloud data, Vendor A successfully developed algorithms to locate and categorize vegetation encroachments within a defined area around a pole. They found the LiDAR data was of good quality and density to support vegetation detection as well as other potential asset related measurements.

To confirm the accuracy of the analytic results, Vendor A used UAS imagery to perform a visual inspection of the five poles selected for this demonstration. The visual inspections confirmed that the analytic results were 100% accurate for detecting vegetation within the defined cylinder area.

6.1.2.2.3 Vendor A Recommendations

This test case was successful and proved the technical risk to a LiDAR-based vegetation encroachment solution is small. Further studies are recommended to determine how this technical capability can be deployed into an existing vegetation management workflow. Recommendations include:

- Quantify the severity of vegetation encroachment by volume or height. This can help estimate the scope of remediation and identify required equipment.
- Use raw LiDAR data that has not been feature-coded. By calculating pole locations from raw data, a significant processing step can be alleviated.
- Use multiple historical LiDAR datasets to identify vegetation growth trends and to recommend brushing frequency or techniques such as mechanical vs. herbicide.
- Use fused RGB/infrared imagery and LiDAR data to identify the health and distance of the encroachment to establishing work order priorities such as dead tree branches within eight feet of cross arms.
- Add the ability to exclude exempt areas such as those with fixed irrigation.

6.1.2.2.4 Conclusions

This test case used LiDAR data to successfully demonstrate how the maintenance audit process can effectively verify poles have been brushed. The technical risk is low. To fully operationalize this workflow, integrating with SDG&E's existing work order management tool will reduce the need for the Vegetation Management team to perform field inspections and enable them to verify work has been performed as expected by outside contractors.

Furthermore, this technology, in conjunction with the automatic detection of at risk poles (using deep learning) can ensure SDG&E complies with California code 4292. This code requires a cylindroid space of 10-feet surrounding each pole that contains a switch, fuse, transformer, or lightning arrestor.

6.1.3 Environmental

6.1.3.1 Identification of Water Bodies

6.1.3.1.1 Approach

Vendor A used the as-built pole information and a vector water layer to identify the distance to the nearest water feature. During the demonstration, Vendor A stated that this capability can be easily expanded to include other layers of interest such as archeological avoids. For this demonstration, a water feature did not exist in the sample area, so one was created.

The distance to water was calculated when the pole information was uploaded to the system. The distance was shown in the terrain section of the Asset Details view (see Figure 21).

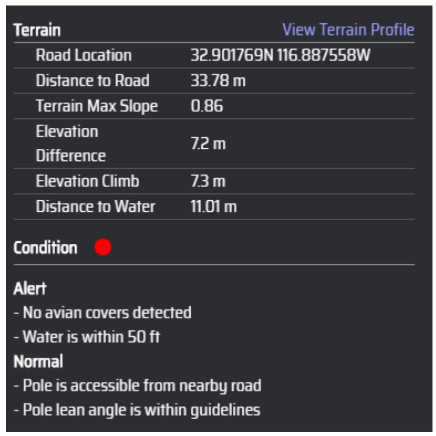


Figure 20: Asset Details View – Distance to Water

The condition was determined by the distance between the pole and the nearest water body as reflected in Table 9:

Indicator	Condition	Distance
Green	Normal	>100 feet
Yellow	Warning	50 – 100 feet
Red	Alert	<=50 feet

Table 9: Water Body Conditions

Like the other layers, the water body layer could be switched on and off accordingly.

6.1.3.1.2 Results

The pole accessibility results were quickly located by conducting a search and filter query. Users can filter against the water proximity condition and the desired severity. The pin color on the map indicated the proximity of a pole to a water feature. Green indicated there is no water nearby, yellow indicated warnings, and red alerted users to when water was less than 50 feet away. Figure 22 shows the search and filter interface when consider proximity to water.

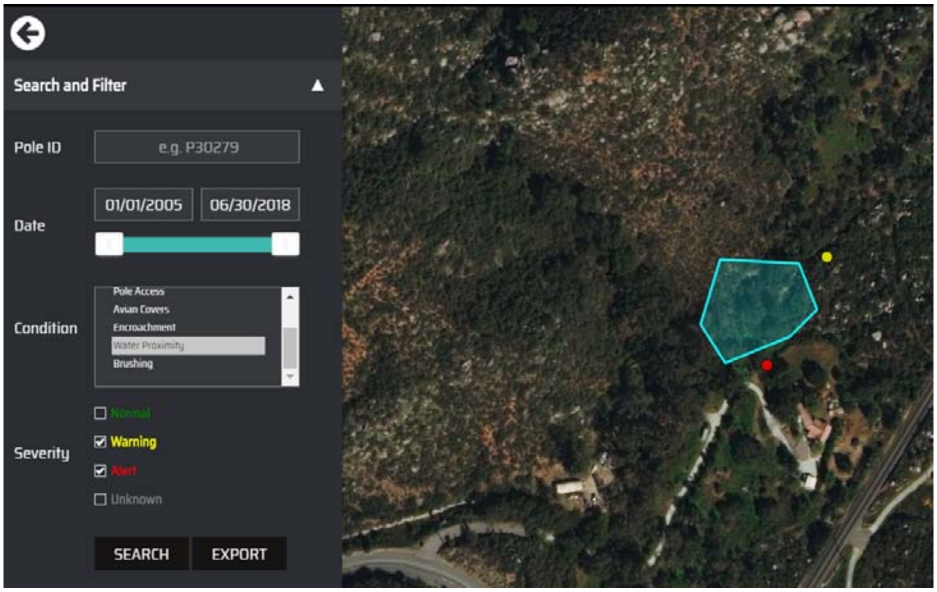


Figure 21: Search and Filter by Water Proximity

Using the pole location provided and a vector layer, analytics were successfully developed to measure the distance from the pole to water feature. The layers provided as a part of the baseline dataset did not contain a water feature in the selected area, so a water layer was manually created by the Vendor A team to be used for demonstration purposes.

6.1.3.1.3 Vendor A Recommendations

Recommendations for further development concerning the identification of water bodies test case include:

- Work with the Environmental Services team to understand additional workflows, user access controls, and security needs.
- Using Open Geospatial Consortium (OCG) standards, provide integration between the Vendor A Tool and GIS systems, for example, layers and results.
- Expand analytics to include additional GIS layers such as archeological avoids.

- Use additional analytics to automatically identify and detect features such as water, marsh areas and other areas of interest.

6.1.3.1.4 Conclusions

Analytics that measure the distance between two objects are easy to implement and operationalize. Integrating the Vendor A Tool with SDG&E's existing GIS systems will provide tremendous value with low risk. The analytics can be easily updated to provide distance information for other environmental layers such as archeological avoids and protective habits. Access to sensitive information can be controlled through user-defined roles. These results will provide the Environmental Services team a more robust view of the areas surrounding a pole and will allow them to engage specialists early in the project planning phase.

6.1.3.2 Pole Accessibility from Road

6.1.3.2.1 Approach

Vendor A used the as-built pole information and vector street layer to identify the distance and path to the nearest road. Since the LiDAR data collected for this area only represented a narrow swath, a United States Geological Survey (USGS) model, a type of Digital Elevation Model (DEM), was added to the system to calculate terrain information including maximum slope, elevation difference, and the overall elevation between the pole and road (see Figure 23).

Terrain	View Terrain Profile
Road Location	32.906926N 116.883829W
Distance to Road	37.57 m
Terrain Max Slope	2.33
Elevation Difference	15.5 m
Elevation Climb	17.6 m
Distance to Water	560.23 m

Figure 22: Terrain Details

Figure 24 shows an example terrain profile. The terrain profile was created to allow users to visualize the topography between the pole and the road.

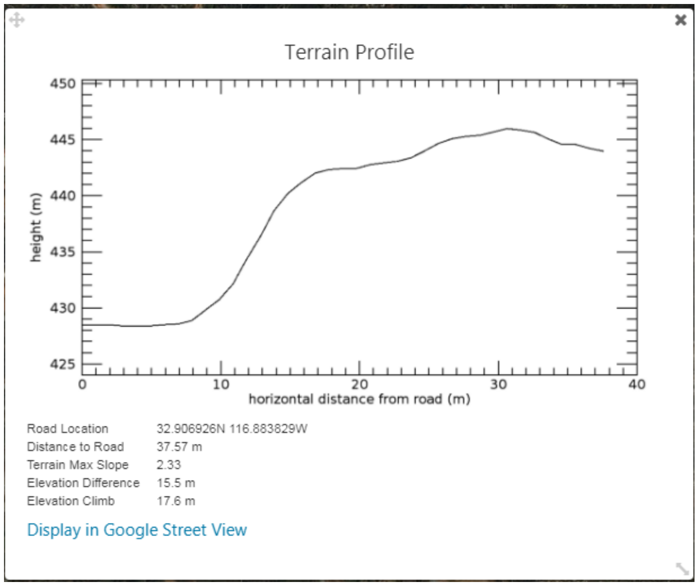


Figure 23: Terrain Profile

The pole accessibility was determined by evaluating the steepness or grade of each point along the path. The grade measures the vertical rise per unit of horizontal run forward. For example, perfectly flat terrain has a grade of "0", and terrain with a 45-degree angle has a grade of "1". With sudden drops and rises in elevation being significant obstacles for access, the largest grade along the path was used to determine the pole access condition. The parameters can be easily amended depending on customer requirements, current parameters are outlined in Table 10:

Indicator	Condition	Grade
Green	Normal	<= 1.2
Yellow	Warning	1.21 – 2.0
Red	Alert	>= 2

Table 10: Pole Accessibility Criteria

6.1.3.2.2 Results

The pole accessibility results were quickly located by conducting a search and filter query. Users can filter against the pole accessibility condition and the desired severity as shown in Figure 25. The pin color on the map indicated if the pole could be accessed from the road. Green specified access was normal, yellow indicated warnings, and red alerted users to when the grade is greater than 2. The blue line shows the path between the pole and the nearest road. Clicking on the blue line displayed the terrain profile.

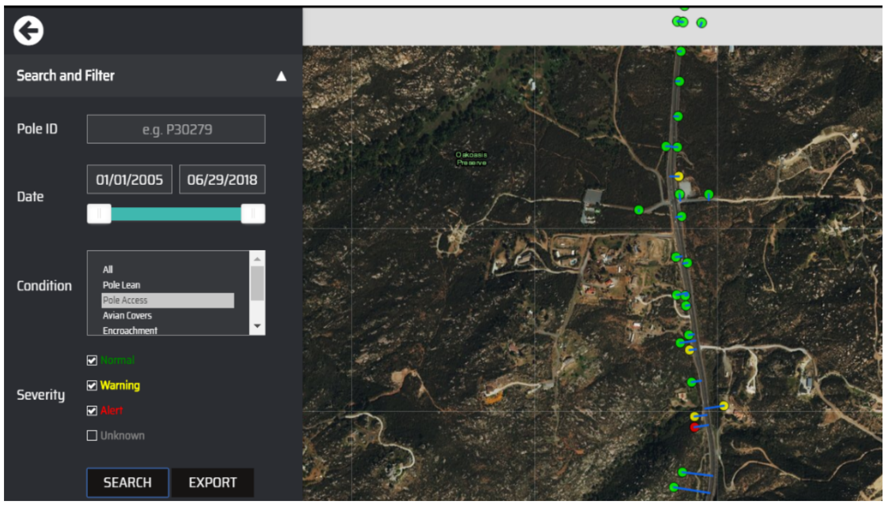


Figure 24: Search and Filter by Pole Accessibility

In addition to the terrain profile and available pole imagery, users could choose to view the pole from the road by clicking the Display in Google Street View link (see Figure 26). A new tab opens in the browser with a view from the road pointing toward the pole (see Figure 27).

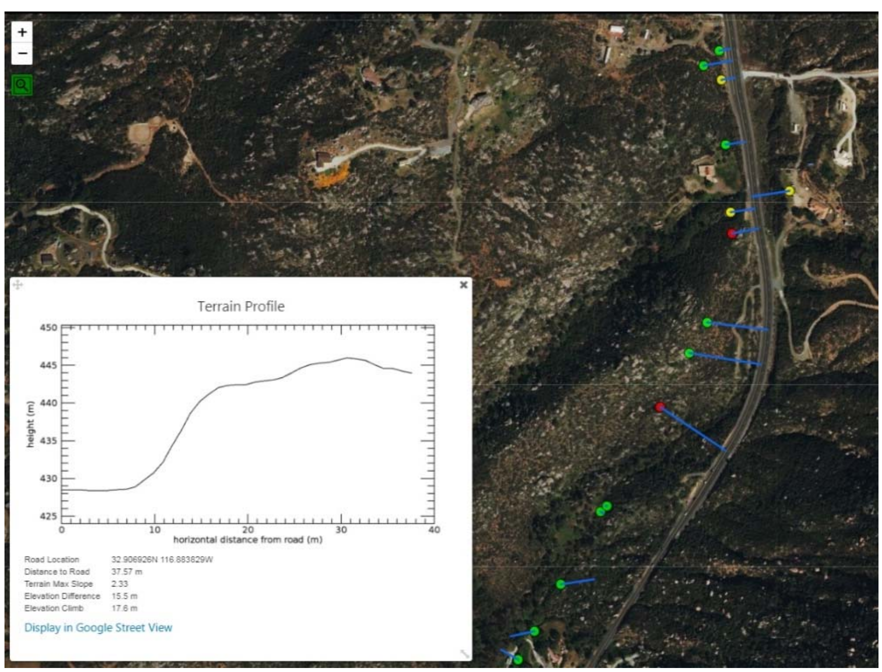


Figure 25: Terrain Profile Map View

The terrain information provided in the asset detail view, combined with the terrain profile and imagery (pole images and Google Steet View), provide valuable insights into the area surrounding the pole.

Figure 26: Google Street View

In addition to exporting road access details, imagery contained within the Vendor A Tool can be saved locally by right-clicking on the image within the Image Viewer as shown in Figure 28.

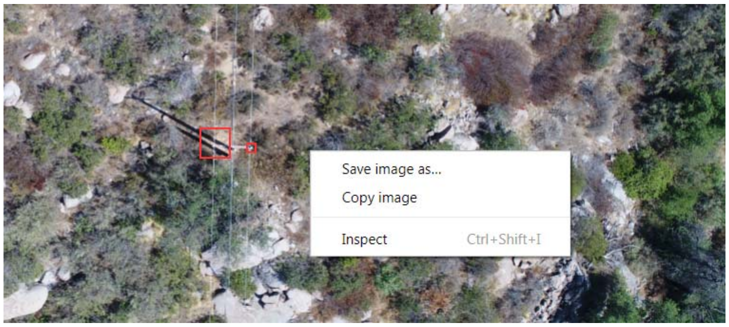
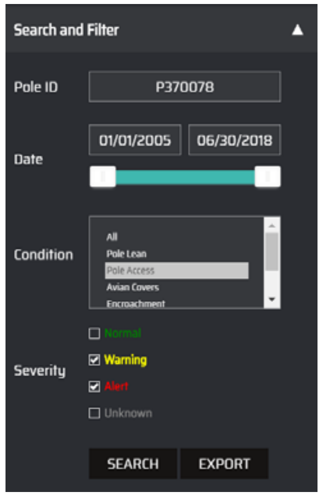
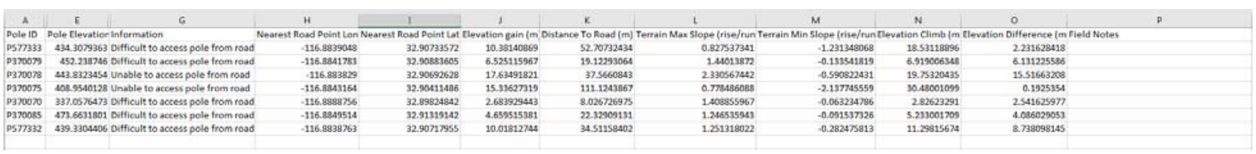


Figure 27: Save Imagery for Inclusion in Project Documentation

Users can also generate a template for capturing field inspection notes. Using the filter and export features, a CSV file containing terrain details for a specific pole or a set of conditions can be created by exporting the pole access results as seen in Figure 29.





Pole ID	Pole Elevation	Information	Nearest Road Point Lon	Nearest Road Point Lat	Elevation gain (m	Distance To Road (m)	Terrain Max Slope (rise/run	Terrain Min Slope (rise/run	Elevation Climb (m	Elevation Difference (m	Field Notes
P577333	434.3079363	Difficult to access pole from road	-116.8839048	32.90733572	10.38140869	52.70732434	0.827537341	-1.231348068	18.53118896	2.231628418	
P370079	452.238746	Difficult to access pole from road	-116.8841783	32.90883605	6.525115967	19.12293064	1.44013872	-0.133541819	6.919006348	6.131225586	
P370078	443.8323454	Unable to access pole from road	-116.883829	32.90692628	17.63491821	37.5660843	2.330567442	-0.590822431	19.75320435	15.51663208	
P370075	408.9540128	Unable to access pole from road	-116.8843164	32.90411486	15.33627319	111.1243867	0.778486088	-2.137745559	30.48001099	0.1925354	
P370070	337.0576473	Difficult to access pole from road	-116.8888756	32.89824842	2.683929443	8.026726975	1.408855967	-0.063234786	2.82623291	2.541625977	
P370085	473.6631801	Difficult to access pole from road	-116.8849514	32.91319142	4.659515381	22.32909131	1.246535941	-0.091537326	5.233001709	4.086029053	
P577332	439.3304406	Difficult to access pole from road	-116.8838763	32.90717955	10.01812744	34.51158402	1.251318022	-0.282475813	11.29815674	8.738098145	

Figure 28: Pole Access Export for Field Notes

The CSV file is editable and can be tailored to meet the needs of the user to capture notes in the field.

Using LiDAR and DEM, analytics were successfully developed to calculate the distance from the pole to nearest road; however, environmental factors that do not appear in these formats, such as chain-link fences, were not detected for this demonstration.

To confirm the accuracy of the analytic results, Vendor A used Google Street View and UAS imagery to perform a visual inspection of the 49 poles provided in the sample dataset. Visual inspections confirmed the analytic results were accurate for detecting access to the nearest road based on the established criteria. To provide a more comprehensive perspective into all potential access points to a pole, Vendor A stated the analytics can easily be extended to include other layers such as known parking lots, dirt roads, pathways and barriers such as fences.

While the sample LiDAR datasets provided were an excellent source for creating DEMs, the coverage was too narrow and did not include nearby roads. To overcome this limitation, Vendor A added a USGS DEM of the circuit to the Vendor A Tool. The DEM was then expanded to include the entire service area.

The DEM enabled the test case to be expanded to include a terrain profile that provides additional insights about the topography and accessibility of the pole from the nearest road. The ability to use DEMs and vector layers to provide these insights highlights the extensibility of the system.

6.1.3.2.3 Vendor A Recommendations

Recommendations for further development concerning the pole accessibility use case include:

- Work with the Environmental Service team to adjust thresholds and rules to meet specific operational requirements.
- Use additional data sources (such as high-quality LiDAR or UAS-derived point clouds) in conjunction with DEMs to identify hard-to-detect obstacles such as chain-link or barbed-wire fences.
- Allow users the ability to update/override pole access conditions.
- Expand export capabilities to allow users to filter results to a specific area or the map extents currently displayed.
- Expand analytics to include additional GIS layers such for consideration such as roads, paths, and parking lots.
- Identify and classify access restrictions such as foot access only, small trucks, or larger vehicles.
- Locate alternative paths to a pole when straight-line road access is difficult (see Figure 30).

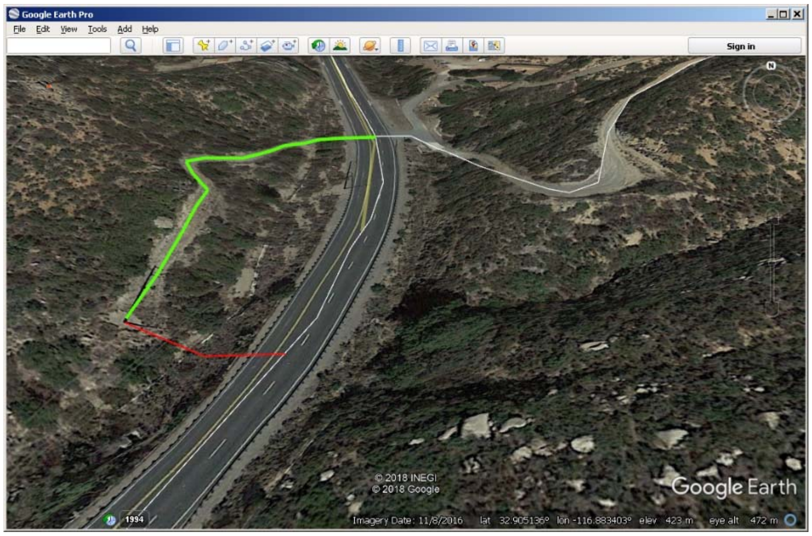


Figure 29: Alternative Path Analysis

6.1.3.2.4 Conclusions

This test case proved layers and elevation data can be successfully used to calculate distances and evaluate access to poles; however, to make this more compelling, the Vendor A Tool should be integrated with the SDG&E GIS system of record. This integration will allow for additional layers to be used by the analytics to provide a more robust view into the areas surrounding a pole. These layers, along with the ability to download images to local desktops and terrain insights, will reduce time spent gathering data for creating map books and performing visual inspections in the field.

6.1.4 Documented Use Case Recommendations

The use cases described in this section were not included in the demonstration due to limitations in the baseline dataset as well as time and budgeting shortfalls. Vendor A have outlined their recommended approach for each below.

6.1.4.1 Vegetation Management - Identifying Hardware and Firebreaks

To conduct a useful proof of concept in the future, the following approach is recommended:

- Use deep learning to locate non-exempt equipment on the pole using still imagery. Non-exempt equipment includes universal fuses, open link fuses, enclosed cutouts with universal fuses, solid blade disconnects, in-line disconnects, lightning arresters, non-porcelain lightning arresters, hot tap clamps, split bolt connectors, fargo connectors, LM connectors, grasshopper air switches and transmission air switches.

- Identify a circuit that contains similar types of components, specific types of lightning arrestors, hot clamps and other equipment.
- Engage subject matter experts to correctly identify and label an initial set of selected components.
- Use the properties of the selected components to define collection requirements such as the number of images, distance from pole, resolution and collection geometry (orbiting or nadir).
- Collect imagery according to the defined specification.
- Label training data for each object of interest.
- Develop and test deep learning algorithms and classifiers against a reserved dataset.

6.1.4.1.1 Conclusions

Once the deep learning models have been developed and tested, the algorithms can be set up as on-ingest processes in the Vendor A Tool. In addition to using imagery for identifying the components, the brushing analytics (firebreak maintenance audit test case) would require LiDAR data for the same poles used for the deep learning portion. The logic for determining condition and severity can be easily updated to support this new workflow.

The technique for locating objects on a pole and identifying vegetation points within a firebreak are analytics Vendor A has successfully proven. To successfully complete this proof of concept, advanced planning and collaboration will be required between SDG&E and Vendor A.

6.1.4.2 Environmental Services – Identification of Staging Yards

To conduct a useful proof of concept going forward, the following approach is recommended:

- Ingest a LiDAR dataset for the entire area around assets. This data must extend beyond the corridor of interest.
- Process the LiDAR point cloud as follows:
  - Classify points to identify terrain, vegetation, buildings, and power lines.
  - Create a DEM by extracting bare earth points from the point cloud.

- Calculate a surface normal for each bare earth point (see Figure 31).

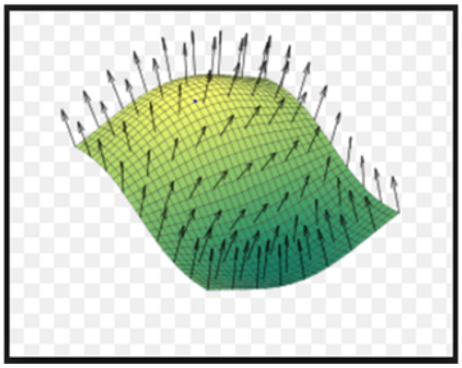


Figure 30: Surface Normal Model

- Search for areas of terrain that meet the following criteria:
    - The area is relatively flat as measured by the uniformity of the surface normals of the ground and slope.
    - The site is a minimum of two acres.
    - The site is clear and free of non-terrain points above ground such as buildings, tall vegetation, and trees.
    - The area is within two miles of the construction site.
    - There are no buildings nearby.
    - The site must be easily accessed from a nearby road.
- Create a polyline for suitable areas. A polyline is a continuous line composed of one or more line segments.
- Display potential sites on a map in the system and make them available as a downloadable shapefile (see Figure 32).

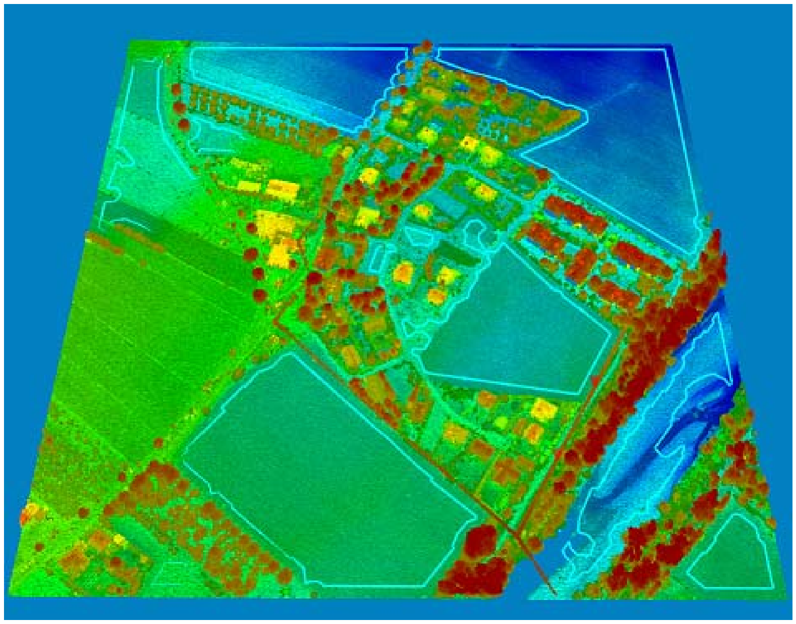


Figure 31: Potential Staging Yards

- Metrics are computed and stored as metadata and displayed. They include:
  - Acreage
  - Maximum slope in area
  - Distance to construction site
  - Distance to nearest power line

6.1.4.2.1 Conclusions

The technique for identifying potential staging yards is similar to existing analytics Vendor A has already successfully developed for locating potential helicopter landing zones for the military. The technical risks are low to make this workflow operational. Once requirements are understood for identifying potential pole sites, this capability could be expanded to automatically identify potential sites as well.

6.1.5 Vendor A System Recommendations

The recommendations outlined below were discussed and presented by the stakeholders during the Vendor A demonstration and apply to the Vendor A Tool.

Camera Direction

To allow the users to have a better idea of the conditions in an area of interest, the vendor system should show what direction the camera was facing when an image was taken.

Pole Lean Visual Indicator

Add a visual indicator to the map to show the angle of pole lean away from 90 degrees.

6.1.6 Vendor A Project Summary

With consumer reliability expectations high, tolerance for power outages low, and operational expenses under scrutiny, utilities are under pressure to leverage newer forms of technology to manage their asset infrastructure more effectively. This series of EPIC projects has allowed Vendor A to demonstrate how a remote sensing data management system coupled with sophisticated geospatial analytics technology can be an effective solution for gaining intelligence on network infrastructure.

In this proof of concept, the executed test cases expanded the use of the Vendor A Tool to include UAS imagery, LiDAR, publicly available elevation data, and supporting data related to assets. The on-ingest analytics successfully delivered actionable insights to several functional groups, incorporating a web-based client application with advanced viewing and reporting capability that emphasized the versatility of the overall system. An initial integration use case was developed, and other opportunities were highlighted that described how data residing in disparate SDG&E systems could be leveraged in this environment.

6.2 Vendor B Test Case Results

6.2.1 Infrastructure

Vendor B chose to tackle the overall Infrastructure use case from data ingestion through to data removal. Their demonstration showed how the Vendor B Tool can be used as a single, central repository to manage data throughout the full data lifecycle.

The Vendor B data model is an incremental loading and delivery data model. The data is loaded or unloaded by generating ADD, MODIFY, or DELETE records. During loading, objects are created in the database by auctioning ADD records. Updates to an object (pole, wire, vegetation canopy, etc.) are achieved with MODIFY records. Finally, the life cycle of an object can be ended by publishing and loading into the system DELETE records. This allows for the near-real-time realization of data as it becomes available and allows for refinement of data once it is loaded into the system.

The data model was designed to support multiple surveys of data in the system simultaneously. This means that objects, such as structures, can exist multiple times with different attributes based on their state during a particular survey.

The standard data model utilizes unique identifiers for every data feature (structure, wire, circuit, vegetation canopy segment, etc.). These unique identifiers allow the history of a feature to be tracked from survey to survey (or year to year). This provides a tool to perform longitudinal analysis of infrastructure health. For instance, a pole's lean can be recorded independently over several years with each observation linked to the same physical asset.

6.2.1.1 Data Ingestion

Once Vendor B received the baseline dataset, it was reviewed, processed, and ingested into the Vendor B Tool. The following data was successfully ingested into the vendor tool:

- **PLS-CADD Models** - Using the standardized database structure, assets in the PLS-CADD models were imported into the database. This import included structures, spans, and catenary geometry in one or more weather condition (at survey, maximum operating temperature, and/or maximum sway).
- **LiDAR** – LiDAR data was indexed using a well-known quad-tree spatial indexing algorithm and placed onto Vendor B's LiDAR server's storage space. The indexing allows for the quick selection and extraction of LiDAR data over a given area.
- **Oblique Imagery** – Using the metadata contained in the acquired images (position, attitude, and gimbal orientation) the view of the camera was projected onto a ground model. This projection provides a representation of the coverage of the image. It is then possible to intersect the camera footprints with other features to determine which images

provide a view of the area in question. The images were georeferenced and shown on the map using a camera icon.

- **GIS Layers** – The Environmental GIS layers were sorted and those that had features in the chosen test segment, were successfully ingested into the system.

6.2.1.2 Data Storage

Vendor B's standardized data model supports multiple surveys to allow more than one year's worth of data, or flights, to be stored in the system. All data that is ingested into the system can be stored and retrieved for examination at the request of the end user.

6.2.1.3 Data Visualization

The data that is stored within the Vendor B Tool can be visualized in a variety of ways. During the demonstration, the data was visualized using the methods outlined below:

- Map view – data is georeferenced and shown at the correct location on the map
- Map icons
  - Camera Icon – shown on the map at the place in which the photograph was taken, with an arrow to show camera direction
  - Pole Icons – shown at the correct location on the map and rotated to the angle of pole lean
  - Vegetation Encroachment Polygons – color coded to reflect severity of the encroachment, shown as polygons on the map
  - Tree Health Polygons – color coded to reflect tree health, shown as polygons on the map
- Contour lines – contour lines were produced from the LiDAR included in the baseline data set. Contour lines are shown on the map at 10-foot intervals
- Grid view – the results of any work search or query are shown in a grid view to the left of the map
- LiDAR viewer – the LiDAR viewer is used to view 3D point clouds from within the platform
- GIS layers – the Environmental GIS layers were ingested into the platform and could be turned on or off as required

6.2.1.4 Data Retention and Removal

Data deletions are handled through the same data loading mechanism for adding data. To unpublish (delete) data a copy of the publication that loaded the data is made, and all of the ACTION verbs in each record are changed from ADD or MODIFY to read DELETE. A software tool exists to select a dataset and generate the removal records. This tool can also be scripted in WorkStudio so that a given dataset can be automatically unloaded after a certain period. Similarly, the tool can be scripted from in WorkStudio to allow users to select a dataset and generate the deletion within the application.

6.2.1.5 Conclusions

Vendor B demonstrated how their platform, Vendor B Tool, could be used to manage data throughout the full data lifecycle from data ingestion to data removal.

They successfully showed how the system could ingest all the data provided in the baseline dataset which included PLS-CADD models, LiDAR, oblique imagery and GIS layers and how this data could be stored within their system, which would act like a central repository.

The interface is intuitive and visually pleasing with good use of icons and various means to retrieve data analytics results through means of a work search. Results can be viewed in both a grid view and map view depending on what is most useful for the user's task in hand.
Vendor B Tool is a secure, cloud-based, geospatial solution that also delivers high-resolution imagery and visualization of feature coded LiDAR. Tools are provided to virtually assess imagery and LiDAR and findings can be stored to create a historical log of asset health to assist with comparison works over time.

The Vendor B Tool can be stood up with little IT configuration and is flexible enough to expand to meet storage and usage needs as the SDG&E dataset increases over time.

Nevertheless, there is currently no method for automated data removal in accordance with a data retention policy, however data can be filtered and manually removed from the system by running a script. With some additional development, Vendor B could potentially introduce automated data retention and removal functionality.

With the addition of an automated data retention and removal mechanism, the Vendor B Tool is a strong candidate for the SDG&E central data repository requirement and could be used to manage data through the full data lifecycle.

6.2.2 Vegetation Management

6.2.2.1 Identifying Tree Growth Patterns

6.2.2.1.1 Approach

Vendor B explored the theme of vegetation encroachment to demonstrate this use case. Further work and development is required to identify tree growth patterns.

Using the feature coded LiDAR data and the PLS-CADD models, canopy segments (polygons) were generated representing tree canopies. Measurement distances were then calculated between the polygon and nearest conductor under various conditions (max sag and grow-in, at survey and grow-in, blowout and grow-in, max sag and fall-in, at survey and fall-in, blowout and fall-in). Based on Minimum Vegetation Clearance Distance (MVCD) values, these results are filtered down to only display points of interest in which other actions can be performed using the software, such as viewing associated LiDAR, oblique imagery, and creating an assessment job to review in the field.

Figures 33 and 34 illustrate how the measurement distances are calculated. The grow-in and fall-in distances are calculated in return space. This means they have no context to determine which surface they were reflected from and how they might be related to any other returns.

Figure 33 shows how the grow-in measurement is the distance from each return to the MVCD buffer.

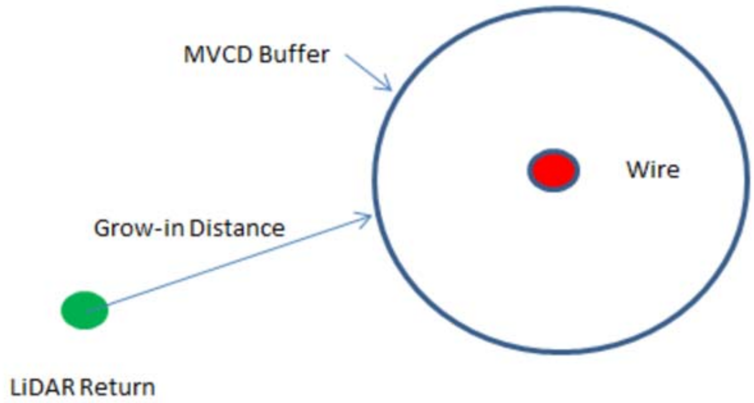


Figure 32: Grow-in Measurement Diagram

Figure 34 below depicts the fall-in measurement. The fall-in measurement is the difference between the return height and the distance from the MVCD to the ground projection of the return. These values are negative for violations.

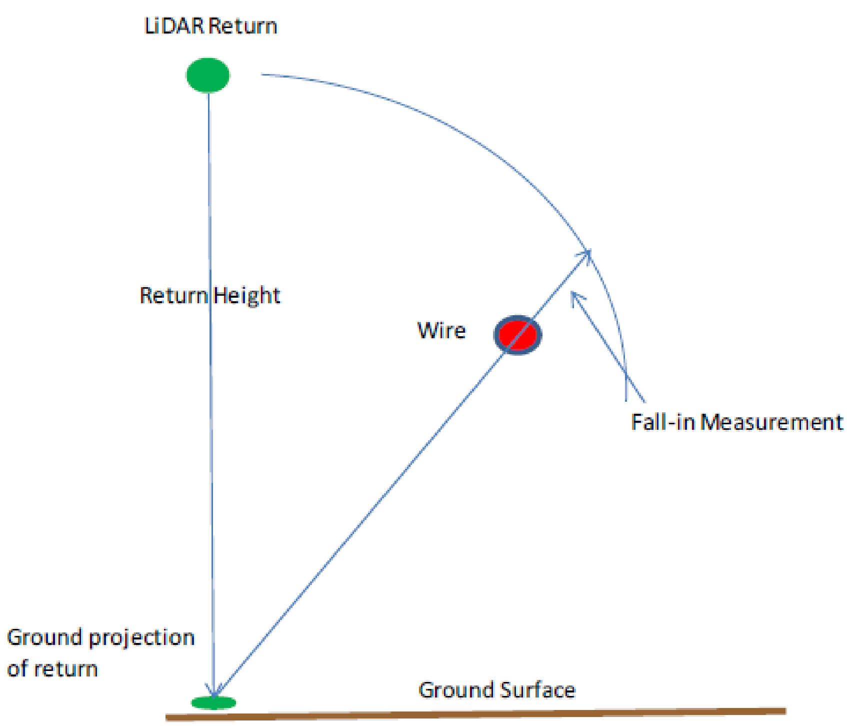


Figure 33: Fall-in Measurement Diagram

Unlike the grow-in/fall-in measurements, the violation height is calculated in canopy segment space. When a canopy segment is located in the same place as the stem and encompasses all of the tree's foliage, it represents the maximum height that tree can attain before it intrudes on the vegetation buffer. It is the best guess on an actual tree falling through the critical zone. Another measure of interest is the wire lift. That is the distance that the wire would have to be lifted to prevent a tree of canopy segment height from intruding into the vegetation buffer.

Figure 35 shows the violation height is the distance from the ground projection of the canopy segment centroid to the MVCD buffer. This is how tall a tree with a stem located at the canopy segment centroid would have to be to strike the MVCD buffer.

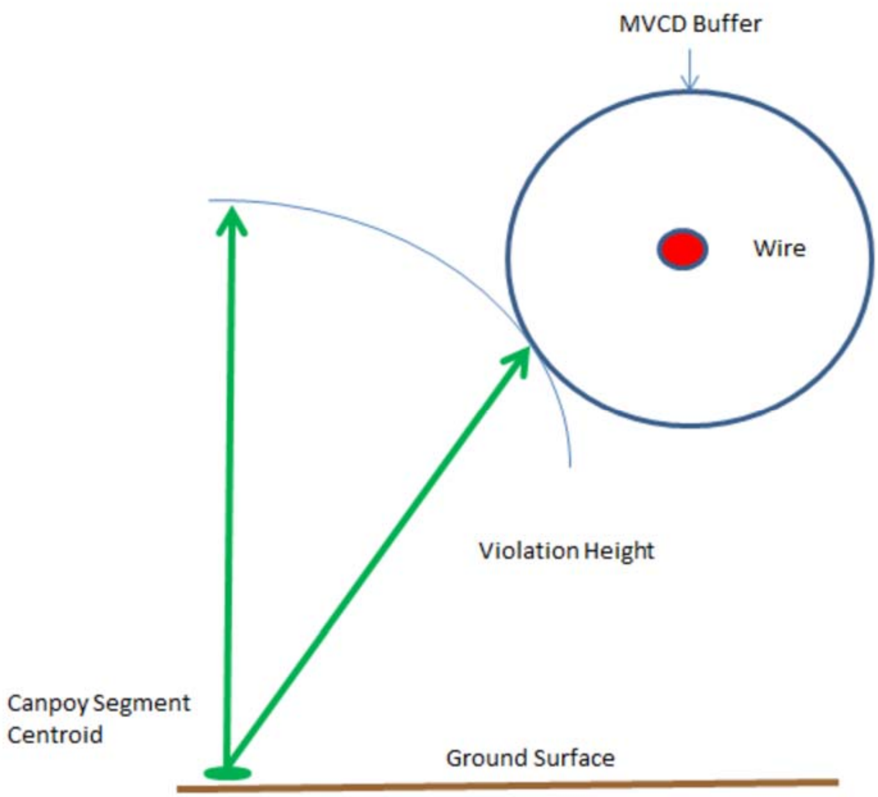


Figure 34: Violation Height

6.2.2.1.2 Results

The Vendor B Tool was successfully able to identify areas of vegetation encroachment, but further development of predictive analysis mechanisms is required to identify tree growth patterns.

The thresholds for encroaching trees can be customized according to customer specifications and encroachment can be conducted on any polygon. Work searches can be filtered based on the survey, voltage (kV), circuit, minimum clearance (ft), maximum clearance (ft), clearance type, right of way (not included in baseline dataset), within right of way (not included in baseline dataset), measurement case, wire safety and work order.

Once the search is conducted, color coded polygons appear on the map that show the different breakdowns for clearance values, the results are also shown in the grid view (see Figure 36). The criteria for encroachment values and color coding can be amended according to customer thresholds. The encroachment can also be observed within the LiDAR viewer (see Figure 37).

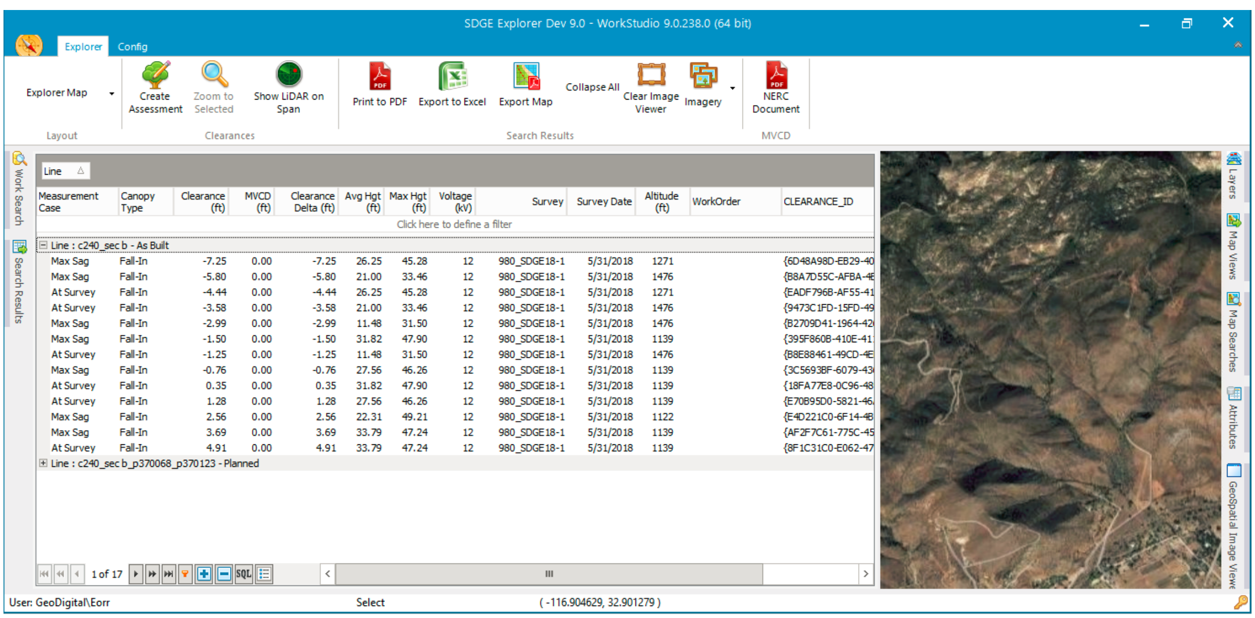


Figure 35: Vegetation Encroachment Results

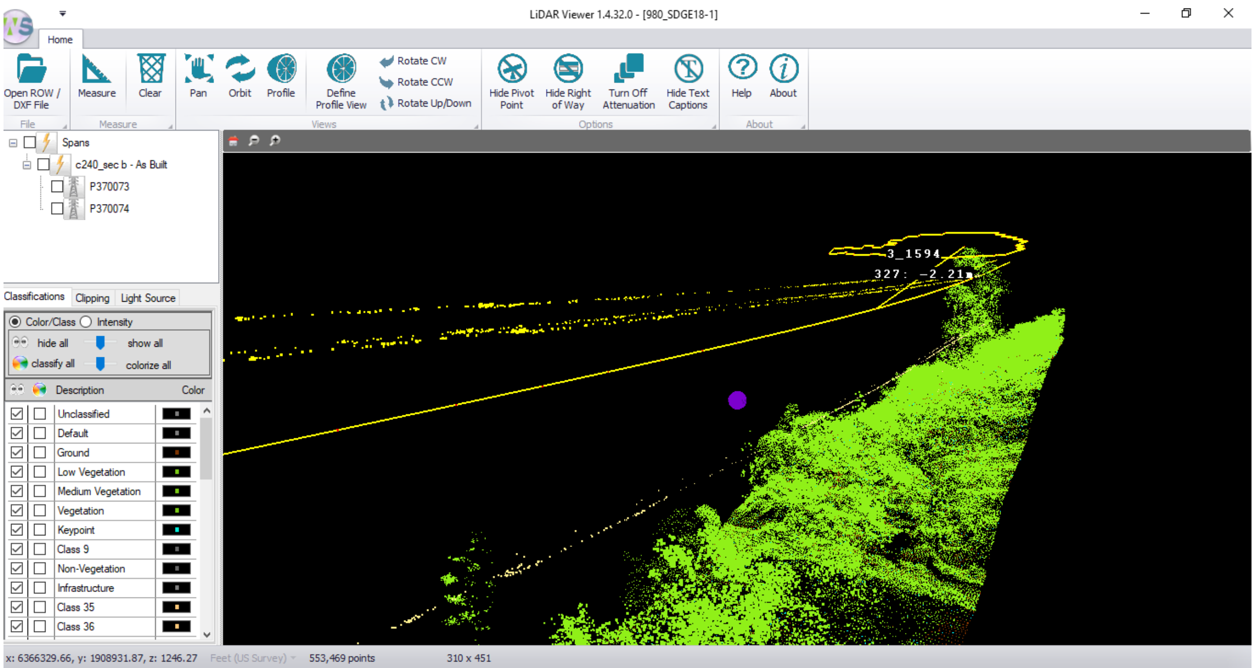


Figure 36: LiDAR View of the Encroachment

6.2.2.1.3 Conclusions

The Vendor B Tool was successfully able to identify areas of vegetation encroachment, but further development of predictive analysis methods is required to identify tree growth patterns.

Predictive analysis of tree growth patterns would assist Vegetation Management with planning their cutting and pruning maintenance schedule and allow for a more efficient process with reduced non-compliances.

6.2.2.2 Identifying Areas of Tree Health

6.2.2.2.1 Approach

LiDAR data and imagery were used to produce a classification of the canopy to show tree health. Typically, foliage is classified into three classes healthy (G), unhealthy (R), and dead (D). A manual classification based on true color imagery, orthographic and, as necessary, oblique imagery was conducted. It is important to note that unhealthy and dead foliage can occur on healthy trees in the autumn and winter when the leaves are senescing. Thus, images collected too early in the spring or too late in the fall will produce spurious results.

The data for this process, produced from the LiDAR survey, consists of canopy segment geometry and pixel color summaries for the canopy segments.

6.2.2.2.2 Results

Vendor B’s platform was able to identify and categorize areas of the canopy to show tree health. This use case was delivered in the form of a work search and Figure 38 shows how the results were both listed and displayed on the map as polygons with a corresponding color code to reflect the health of the trees in a particular area.

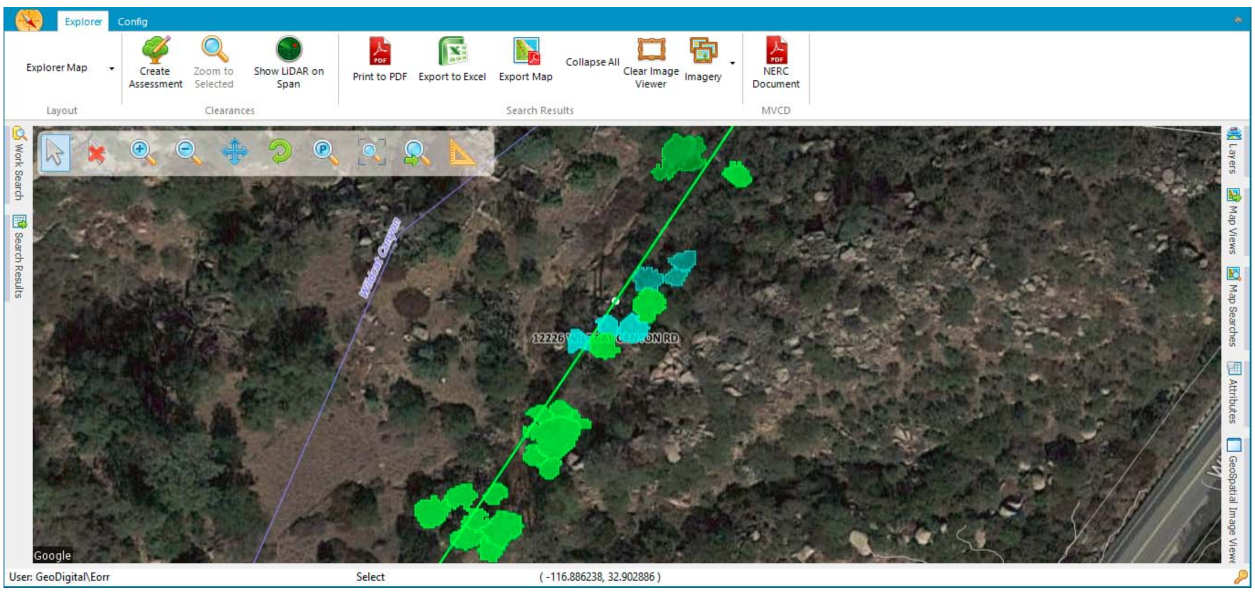


Figure 37: Tree Health Map

Infrared data was not supplied as part of the baseline dataset and the analysis was conducted using LiDAR and imagery data alone. Infrared data can be used as a means to measure tree health since healthy vegetation absorbs red and blue light for photosynthesis resulting in the reflection of more shortwave infrared light than visible green light. When a plant becomes unhealthy, it reflects more of the visible red light and less of the invisible infrared. Figure 39 depicts healthy vegetation infrared absorption and reflection.

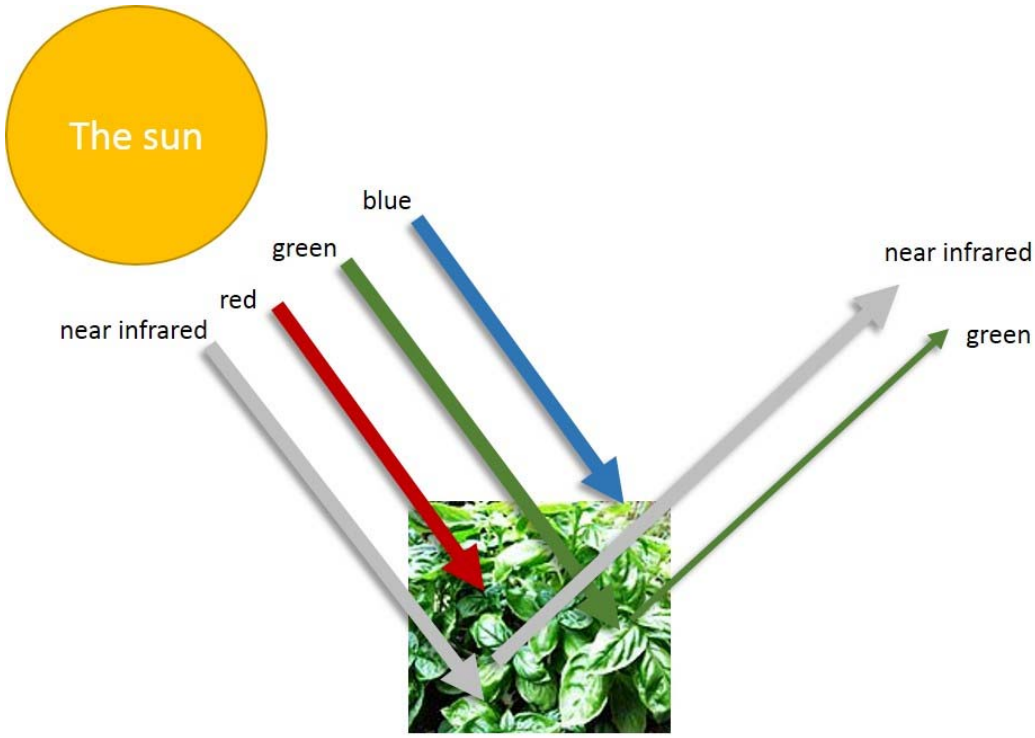


Figure 38: Healthy Vegetation Infrared Absorption and Reflection[7]

If infrared data were to be provided, the accuracy and reliability of the tree health results would be significantly improved.

6.2.2.2.3 Conclusions

Vendor B's platform was able to identify and categorize areas of the tree canopy to show tree health. The analysis was carried out manually based on true color imagery, using orthographic and oblique imagery. LiDAR data was also used to determine the canopy segment geometry and pixel color summaries for each segment. The results were shown as polygons on maps and a color coded depending on the perceived health.

Since this analysis was conducted through means of a manual classification, there is room for human error and inconsistency of results. Automated analytical methods should be developed to improve accuracy and reduce the time burden associated with manual analysis.

[7] DAI Remote Sensing Part 3: Identify Healthy Vegetation from Space. Retrieved from: https://dai-global-digital.com/lush-green-remote-sensing.html

In addition, the results would be greatly improved if infrared data was supplied by SDG&E as part of the baseline dataset.

6.2.2.3 Identifying Changes in Pole Lean

6.2.2.3.1 Approach

Each pole in the subject area was analyzed using the LiDAR point cloud. The analysis extracted the coordinates of two points along the middle of the pole. The height above ground for these two points (H_1 and H_2) were recorded as was the Euclidean distance between (L) the two points.

These three values were utilized to calculate the lean of the pole. The simple trigonometric relationship states that the lean of the pole is found to be arc cosine of the ratio of the differences in heights above ground (H_2-H_1) to the length (L) of the vector.

6.2.2.3.2 Results

The findings were made available in a work search where a user could filter poles to only show those greater than 7 degrees or filter against a particular survey or structure name. The results were viewed in the results tab which gave a grid view of all the poles that match filtered criteria. The pole icon displayed on the map was also rotated the value of the lean and one pole was found to have a lean of more than 7 degrees (see Figure 40).

The Vendor B team stated that the pole lean thresholds can be customized, and color coded depending on the severity of the lean and the customer requirement. A red, yellow and green ‘traffic light’ type system could be used to quickly determine the pole lean criticality.

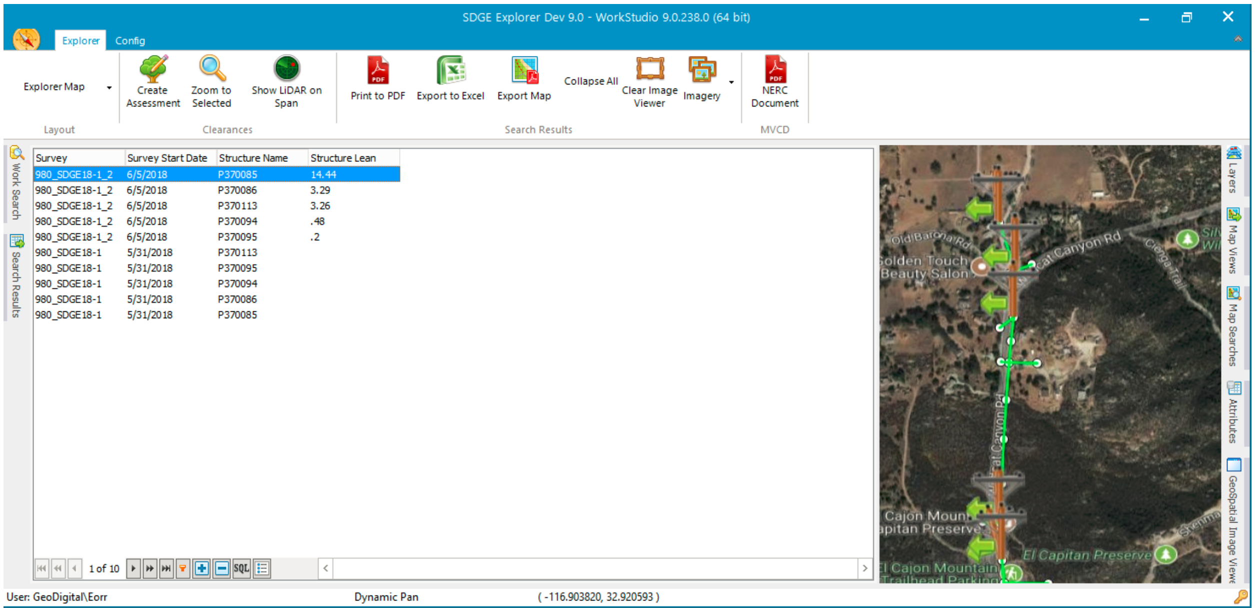


Figure 39: Pole Lean Results

6.2.2.3.3 Conclusions

The Vendor B Team successfully identified changes in pole lean using their developed methods to calculate the degree of lean from perfectly straight (90-degree angle).

This test case proved that the pole angle can be calculated using the LiDAR point cloud data and displayed in the map and grid view as meaningful results for users.

6.2.3 Environmental

6.2.3.1 Pole Accessibility from Road

6.2.3.1.1 Approach

Using the LiDAR provided by SDG&E, the Vendor B team produced contour lines at 10-foot intervals and applied smoothing and simplification. The results were then added to the map. Using the contours combined with ortho imagery, oblique imagery, and other GIS layers users are able to assess the pole accessibility remotely.

The system also has functionality to add field notes, for example to inform other personnel of the presence of a gate or other obstacle. Once this information is digitalized, it becomes available to all other users.

6.2.3.1.2 Results

The user is able to search against the pole of interest and zoom in to this area on the map. When zoomed in sufficiently, the contour lines become visible. The measuring tool can be used to measure the distance from the pole to the road and a determination of the terrain and elevation can made by manually studying the contours as shown in Figure 41. The system does not provide a terrain profile or automatic calculation of the distance of the pole from the roadway. However, the Environmental Team could see value in having access to the contour line information and measuring tool as part of their initial desktop assessment.

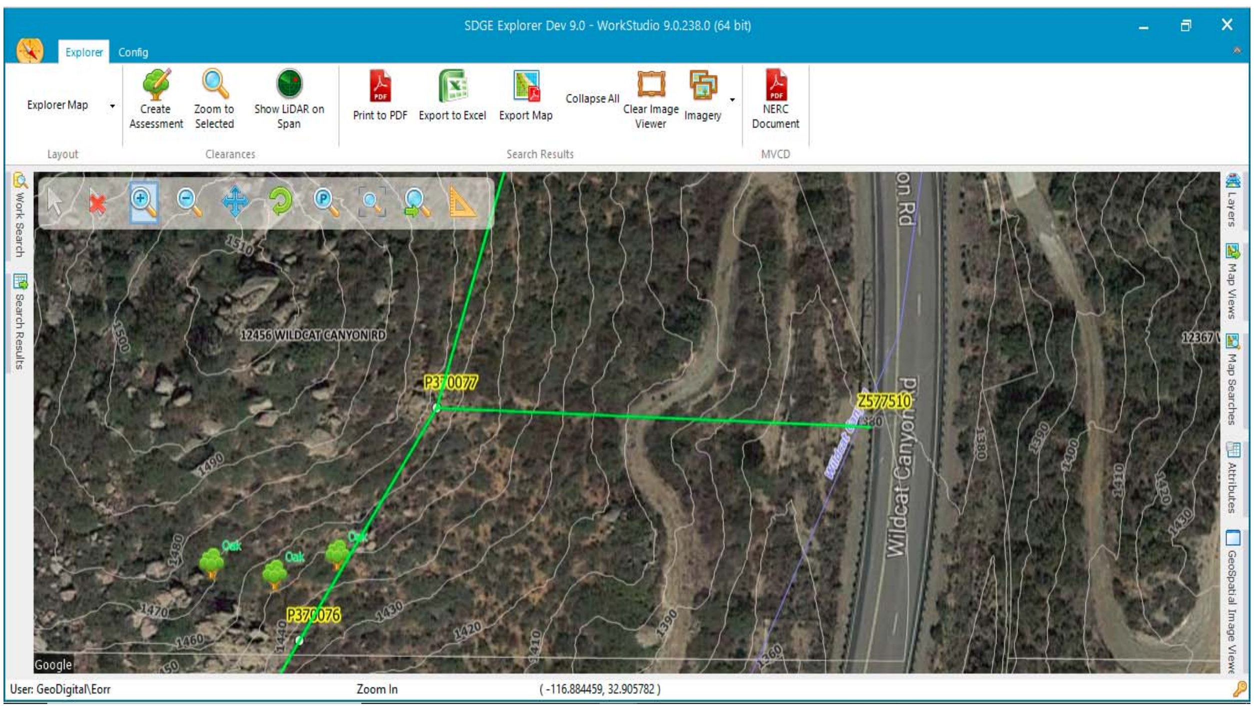


Figure 40: Pole Accessibility from Road

6.2.3.1.3 Conclusions

Vendor B successfully created contour lines from the LiDAR data provided by SDG&E and plotted these on the map at 10-foot intervals. Measurement tools were provided to measure the distance between the pole and the road and the contour lines could be studied to gain knowledge regarding the incline and decline along the route.

More value would be added to the user if a terrain profile was generated to give users a quick visual of the expected terrain and if distance from the roadway to the pole was automatically calculated without the need to use measuring tools on the map.

Vendor B could build upon this use case in the future to provide alternative paths to the poles, for example focusing on the easiest route on foot or the best route to take a vehicle, as opposed to a direct straight line.

6.2.3.2 Capture of Pole Accessibility Field Notes

6.2.3.2.1 Approach

Users are able to generate an 'assessment job' within Vendor B Tool that can be assigned to any user in the system. The assessment job is used to identify and describe the type of work that is due to be carried out in the field. Once the server has created the job, the assignee is able to sync the job to their mobile device to take into the field. Once in the field, assessment related notes, comments, observations, pictures and such like can be recorded and saved to the job.

When the user re-connects to a network (cellular or Wi-Fi), the job can be synced back to the server to make all information collected available to other users. A workflow can also be followed to transition the job from one group or user to another to enforce data integrity.

6.2.3.2.2 Results

The Vendor B Team successfully demonstrated the creation of an assessment job, showed how the job could be synced to a mobile device, executed and re-uploaded to the Vendor B Tool (see Figure 42). All teams could see value in this functionality, particularly the Environmental Team, due to the huge time and efficiency saving potential.

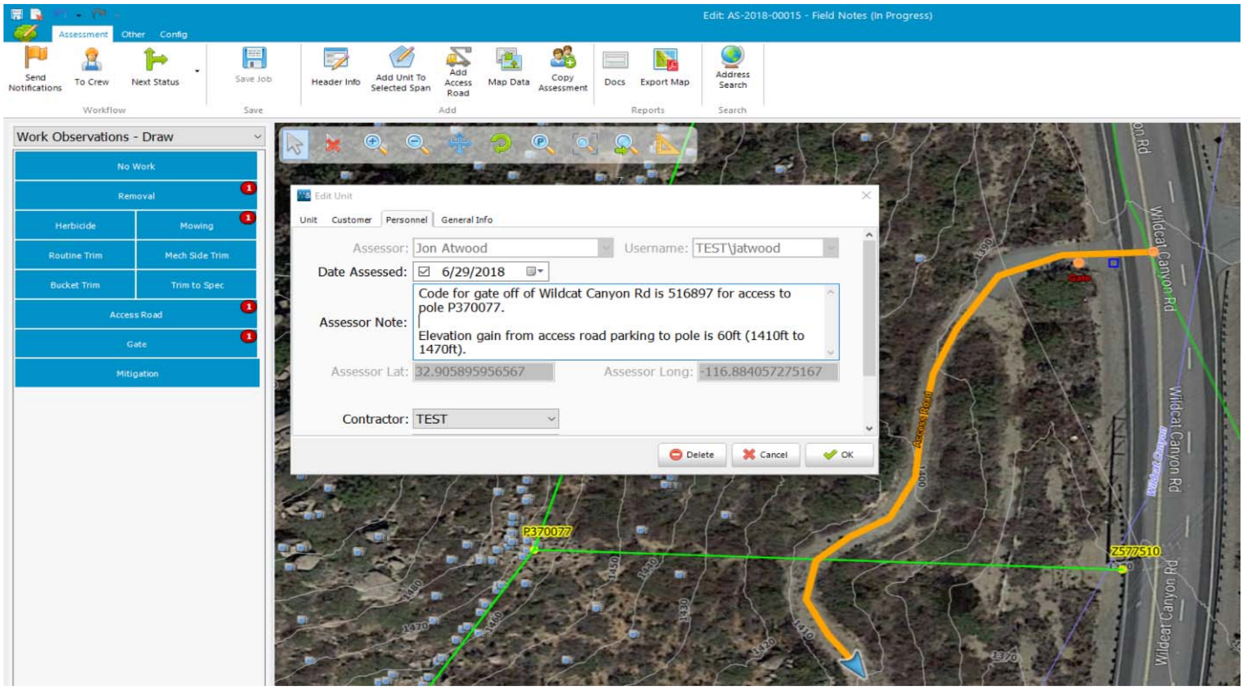


Figure 41: Field Notes Example

6.2.3.2.3 Conclusions

Vendor B showed how the Vendor B Tool could be extended to provide mobile functionality. The Vendor B Team successfully demonstrated how an assessment could be created and completed on a mobile device, such as a tablet. This provides tremendous benefits for in-field data collection. Where there is no network service, the assessment is synced back to the server when connection is re-commenced.

All stakeholders could see the benefits that in-field mobile data collection could bring, and this capability should be considered by SDG&E for implementation in the near future.

6.2.3.3 Vendor B Recommendations

Vendor B did not submit individual recommendations for each test case that was demonstrated, however they did submit an overall recommendation for the EPIC project which is outlined below.

Vendor B recommend that SDG&E define and develop a system security policy to allow users that are assigned specific roles and belong to certain groups privileges and access that match their needs. This is known as role-based access control (RBAC). In order to do this, roles must be defined for various job functions then the permissions to perform certain operations are assigned to specific roles. Since users are not assigned permissions directly but only acquire them through their role, management of user rights is simplified.

Since the Vendor B Tool can be configured to handle many other use cases or data analytics, Vendor B would like to hold more meetings with stakeholders to further define the additional use cases and associated workflows that were discussed during the various stakeholder meetings. This would allow stakeholders to make a determination of whether the platform could be a good fit in SDG&E's current environment.

6.2.4 Documented Use Case Recommendations

The use cases documented in this section were not included in the demonstration due to limitations in the baseline dataset as well as time and budgeting shortfalls. Vendor B have outlined their recommended approach for each below.

6.2.4.1 Vegetation Management - Identifying Hardware and Firebreaks

Vendor B propose to tackle this use case using LiDAR, obliques and GIS data. An analysis of the imagery would take place to identify hardware on the poles from a list of known assets. Firebreaks would be identified by analyzing both the LiDAR and imagery. A work search would be created to return the results from the analyses which would be shown on both the map and in the grid.

6.2.4.2 Environmental Services - Identification of Potential Pole Sites

In order to execute this use case successfully, more information is needed regarding the requirements for a potential pole site. At a minimum, Vendor B would need imagery and parcel information, as well as site specific criteria. It is likely that the analysis would be carried out manually and a work search would be created to return the results.

6.2.4.3 Environmental Services - Identification of Vegetation Community

Vendor B would use LiDAR and obliques to conduct a manual analysis of vegetation type by comparing with known sources. Where possible, obscure or unknown vegetation type found in imagery would be verified by a subject matter expert. A work search would be created to return the results.

6.2.4.4 Environmental Services - Identification of Birds' Nests on Poles

Initially, Vendor B proposed to use oblique imagery to view the poles and possible nests. An analyst would manually assess each image to check for the presence of a bird's nest and a GIS layer would be created to display the results. Once enough imagery was collected, the assessment process could be automated.

6.2.4.5 Environmental Services - Identification of Noxious Weeds and Invasive Species

LiDAR and oblique imagery would be used as part of the identification process. An analysis would be set up, with defined parameters that could be run. Results would show visually on the map and in the grid by means of a work search.

6.2.4.6 Environmental Services - Identification of Staging Yards

To begin with, Vendor B proposed to use oblique imagery to manually identify staging yards according to the criteria defined by SDG&E. An analyst would manually assess each image to check for suitable areas and a GIS layer would be created to display the results. Once enough imagery was collected, the assessment process could be automated.

6.2.4.7 Environmental Services - Comparison of Pre- and Post-Construction Work Areas

Vendor B would use LiDAR, obliques, GIS and PLS-CADD data to make the comparison between pre- and post-construction work areas. This would be handled by manually assessing the data and identifying differences in the areas over time. A work search would be created to allow the users to view and filter the results.

6.2.4.8 Documented Use Case Conclusions

Vendor B provided low-level approaches and recommendations for the documented use cases that were not included as part of the final demonstration. These included the following:

- Vegetation Management
  - Identifying Hardware and Firebreaks
- Environmental Services
  - Identification of Potential Pole Sites
  - Identification of Vegetation Community
  - Identification of Birds' Nests on Poles
  - Identification of Noxious Weeds and Invasive Species
  - Identification of Staging Yards
  - Comparison of Pre- and Post-Construction Work Areas

For all these use cases, the main approach involves the manual assessment of data to produce results. There is potential to automate some of the processes once enough data has been collected. Manual assessments of data, although useful, can introduce human error and inconsistency, which in turn reduces accuracy.

Automating the analytics and introducing machine learning to produce accurate results and analytics quickly and consistently, would be a useful capability addition to the Vendor B Tool.

6.2.5 Vendor B System Recommendations

The recommendations outlined below were discussed and presented by the stakeholders during the Vendor B demonstration and apply to their tool.

View Images from LiDAR Viewer

It would be useful if a user could view images directly from the LiDAR viewer for further clarification, for example, this may allow a user to determine what species a tree is or get a clearer idea of the terrain.

Terrain Profile

Although the vendor system contained contour lines that were derived from LiDAR, there was no mechanism to automatically determine the distance and gradient to a pole when considering its accessibility, this had to be done manually by the user. Ideally, the system would calculate this automatically and display it as a terrain profile as shown in Figure 43.

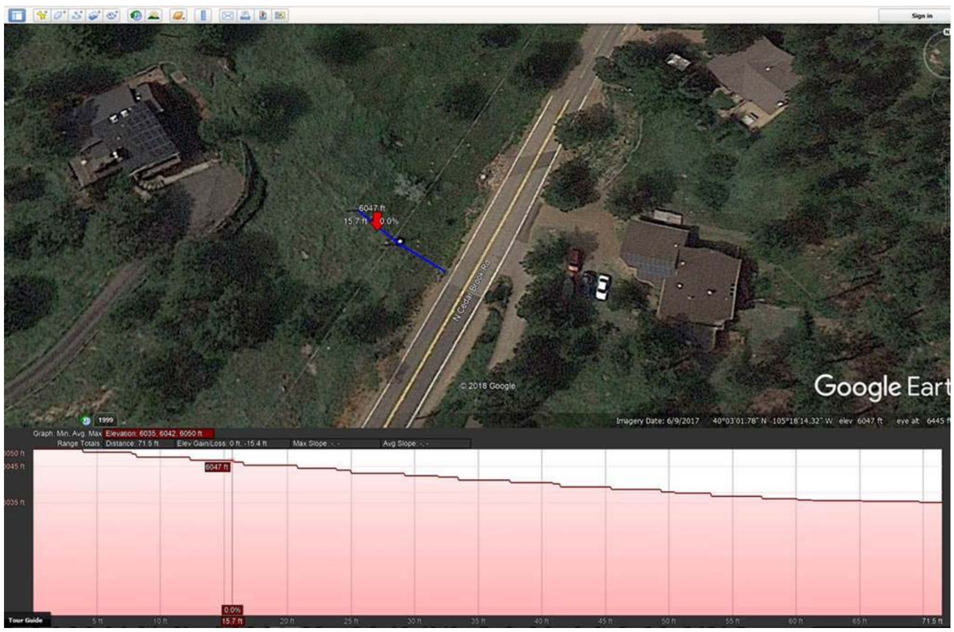


Figure 42: Terrain Profile and Grade from Pole to Nearest Roadway[8]

Tree Growth Patterns

Although Vendor B were successfully able to demonstrate vegetation encroachment during this round, they did not demonstrate or document how they would build upon this to identify tree growth patterns. Tree growth pattern analysis is an extremely important tool that can be used to assist the Vegetation Management Team with planning their maintenance works. Vendor B may consider further research and development of tree growth pattern analysis, if they are selected as a vendor in future EPIC projects.

Develop Machine Learning Tools

[8] Image taken from Google Earth. Retrieved from: https://earth.google.com/web/

Vendor B's recommended approach for future use cases are focused on manual analysis, where an analyst will pore through a dataset, for example oblique imagery, looking for a feature of interest. Vendor B should consider developing or outsourcing machine learning techniques to carry out this analysis to reduce the time burden and improve accuracy and confidence of results.

Automatic Retention and Removal Mechanism

Data that is ingested into the Vendor B Tool is stored indefinitely until an administrator goes in and manually deletes the information. A workflow should be implemented where retention periods could be set on ingestion, and the data be automatically removed once they elapse. Overall data management would be improved, removing redundant data improves system performance and makes it easier for the user to find what they are looking for.

6.2.6 Vendor B Project Summary

With SDG&E looking to introduce innovative technologies to improve business processes and increase efficiency, this EPIC project has allowed Vendor B to showcase the Vendor B Tool. Vendor B Tool could be used as a single, centralized repository for the vast plethora of SDG&E data and has functionality to manage the data throughout the full data lifecycle from collection to removal.

Vendor B showed how their system could be used to conduct the required analytics to accomplish meaningful results for the test cases. With further discussion with the stakeholders, additional analytics could be developed to incorporate different use cases, datasets and work searches to meet the needs of SDG&E end users.

7.0 Requirements for Prospective SDG&E System

This section outlines the vendor-neutral requirements for a prospective SDG&E system to act as a central repository, with advanced data analytics capabilities, to increase internal efficiency and productivity. The requirements specification is based on how the stakeholders foresee the prospective system working and were captured throughout the use case development process. This requirement specification is designed to be used as a basis for any full-scale commercial deployment of such system that may occur in the future.

7.1 Requirements Specification

The prospective system requirements have been categorized into functional (general, system services, mobile data capture, advanced analytics), non-functional and collection requirements and are outlined below.

7.1.1 Functional Requirements - General

ID: FR1

Title: Central Repository

Description: All data must be held in a central repository. The repository must be capable of ingesting the following data types: LiDAR, RGB oblique imagery, RGB nadir imagery, RGB video, GIS shape files, Powerworks shape files, PLS-CADD models, ultraviolet data, infrared data, field notes and other supporting documents (PDF, XLS, KMZ, DWG).

ID: FR2

Title: Geospatially Referenced Data

Description: All data must be shown at the correct location on the map. Pins must show where the data is on the map. When a user clicks on the pin, information about that asset or data point must be displayed.

ID: FR3

Title: Draw Bounding Box

Description: Users must be able to draw a search box on the map and all georeferenced data in that area must be displayed. Pins must show where the data is on the map.

ID: FR4

Title: Measurement Tools

Description: Measuring tools must be available to measure distance, area and volume on the map.

ID: FR5

Title: Attribute Fields

Description: Each asset much have associated fields to store attribute data.

ID: FR6

Title: Marker Clusters

Description: Marker clusters must be used to display larger numbers of markers on a map. As a user zooms into any of the cluster locations, the number on the cluster will decrease, and the user will begin to see the individual markers on the map. Zooming out of the map consolidates the markers into clusters again.

ID: FR7

Title: Zoom and Pan

Description: To move the map, users must be able to click and hold the left mouse button and drag the map to an area of interest. Alternatively, the map could be moved north, south, east or west using the pan arrows. The central pan button must re-center the map, returning to the last result.

ID: FR8

Title: File Viewer

Description: Users must be able to view Microsoft Word documents (DOC), Adobe PDF documents (PDF), Microsoft Excel spreadsheets (XLS), video files, picture files, text files and binary files in a file viewer.

ID: FR9

Title: Spatial Layers

Description: The system must have capability to ingest and display spatial layers on a map that can be switched on and off as required. Examples include road layers, aerial imagery and water bodies.

ID: FR10

Title: Pole Centric Data

Description: There must be an option to link data to a pole.

7.1.2 Functional Requirements – System Services

ID: FR11

Title: Data Categorization

Description: Data must be categorized by date/time, by type, by source (camera, UAV, helicopter etc.), by angle (for images) and by x, y, z coordinates (location).

ID: FR12

Title: Search Function

Description: Data must be searchable by a pre-defined keyword, by date, by type, by source and by location.

ID: FR13

Title: Reporting Function

Description: Users must be able to generate reports against selected criteria. Criteria must include pre-defined keywords, date ranges, data type(s), data source(s) and location(s). The full history of each asset should be displayed.

ID: FR14

Title: Download Function

Description: Users must be able to download data and reports from the system in PDF and XLS formats.

ID: FR15

Title: Print Service

Description: Downloaded data must be printable.

ID: FR16

Title: Batch Data Upload

Description: The system must have a bulk upload function to allow large quantities of data to be uploaded from an CSV file in one action.

7.1.3 Functional Requirements – Mobile Data Capture

ID: FR17

Title: Mobile Data Tool

Description: A mobile data tool and customized app must be available for the collection of field data.

ID: FR18

Title: Timestamped Data

Description: All collected data must be time and date stamped.

ID: FR19

Title: GPS Capability

Description: The mobile data tool must have GPS capability to provide geolocational and time information about where and when data was collected.

ID: FR20

Title: Voice Recognition Software

Description: The mobile data tool must have voice recognition capability to allow dictation of field notes.

ID: FR21

Title: Offline Capability

Description: The mobile data tool must have an offline capability that allows data collection when there is no internet connection. Collected data must automatically sync with integrated systems when connection is resumed.

7.1.4 Functional Requirements – Advanced Data Analytics

ID: FR22

Title: Identification of Equipment on Poles

Description: The system must be trained to automatically identify the following equipment on poles; universal fuses, open link fuses, enclosed cutouts with universal fuses, solid blade disconnects, in-line disconnects, lightning arresters, non-porcelain lightning arresters, hot tap clamps, split bolt connectors, fargo connectors, LM connectors, grasshopper air switches and transmission air switches.

ID: FR23

Title: Identification of Firebreaks

Description: The system must be trained to automatically identify firebreaks at pole feet.

ID: FR24

Title: Automatic Measurements

Description: The system must have the capability to automatically measure the radius of the firebreak and flag those that have a radius of less than 10 feet.

ID: FR25

Title: Comparative LiDAR Analysis

Description: The system must have the capability to compare historic LiDAR data with current LiDAR data to identify vegetation growth patterns and pole lean. Poles that lean by more than 10 degrees must be flagged.

ID: FR26

Title: Image Analysis

Description: The system must have the capability to analyze images to determine tree health through color change and calculate pole lean angles. Poles that lean by more than 10 degrees must be flagged.

ID: FR27

Title: Identification of Potential Pole Sites

Description: The system must be trained to identify potential pole sites.

ID: FR28

Title: Identification of Vegetation Type

Description: The system must be capable of identifying and distinguishing vegetation type.

ID: FR29

Title: Identification of Birds' Nests

Description: The system must be trained to identify birds' nests on poles and within vegetation.

ID: FR30

Title: Identification of Noxious Weeds and Invasive Species

Description: The system must be capable of identifying noxious weeds and invasive species and giving a determination of their variety.

ID: FR31

Title: Identification of Staging Yards

Description: The system must be trained to identify potential staging yards according to the following criteria:

- Staging yard should be flat with no more than 5% slope, paved or bare ground
- Staging yard must be within a two-mile drivable distance of the poles
- Staging yard must be at least 2 acres in size

ID: FR32

Title: Identification and Categorization of Pole Anchors

Description: The system must have the capability to identify pole anchors and make a determination of the area in which they fall, for example in a water body.

ID: FR33

Title: Comparison of Pre- and Post-Construction

Description: The system must be trained to identify changes in the environment after construction works have been completed by comparing LiDAR, imagery and other data types.

The system must have the capability to identify vegetation types in the pre- and post-construction surrounding areas and calculate the percentage of native species before and after construction.

ID: FR34

Title: Pole Accessibility from Road

Description: The system must be able to determine the accessibility of a pole from a roadway by considering distance, elevation and other environmental features such as the presence of water bodies.

ID: FR35

Title: Auditing

Description: The system must have functionality to select and analyze a random sample of data for audit.

7.1.5 Non-Functional Requirements

ID: NR1

Title: Simple User Interface

Description: The user interface for both the desktop and mobile app must be intuitive and easy to use.

ID: NR2

Title: Interface to GIS (ESRI)

Description: The system must be integrated with GIS.

ID: NR3

Title: Interface to GEARS

Description: The system must be integrated with GEARS.

ID: NR4

Title: Interface to Powerworks

Description: The system must be integrated with Powerworks.

ID: NR5

Title: Interface to Pole Information Data System (PIDS)

Description: The system must be integrated with PIDS.

ID: NR6

Title: Interface to PLS-CADD

Description: The system must be integrated with PLS-CADD.

ID: NR7

Title: Interface to External Aerial Imagery Source

Description: The system must be able to leverage up to date aerial imagery from an external source and present it in a useable format.

ID: NR8

Title: Bind to SDG&E Security Protocol

Description: The system must bind to the SDG&E access control model.

ID: NR9

Title: Role-Based Access Control

Description: Certain data access must be restricted based on the user's role and privileges.

ID: NR10

Title: Protection of Sensitive Data

Description: Access to cultural data must be restricted to authorized users only through use of a role-based access control model.

ID: NR11

Title: Data Retention

Description: Data must be retained according to SDG&E's data retention policy. For construction, the data must be retained for the life of the construction plus five years. Data should not be purged until it is all out of service. For example, linked assets my still be in service even if the primary asset is not. The primary asset cannot be purged until all its affiliated data is out of service.

ID: NR12

Title: Displaying Pole Accessibility Results

Description: Pole accessibility results must be calculated and displayed according to the following criteria:

Indicator	**Condition**	**Grade**
Green	Normal	<= 1.2
Yellow	Warning	1.3 – 2.0
Red	Alert	>= 2.0

ID: NR13

Title: Displaying Distance from Water Body

Description: The distance from a water body must be calculated and displayed according to the following criteria:

Indicator	**Condition**	**Distance**
Green	Normal	>= 100 ft
Yellow	Warning	51 – 99 ft
Red	Alert	<= 50 ft

ID: NR14

Title: Displaying Pole Lean Results

Description: Pole lean must be calculated and displayed according to the following criteria:

Indicator	**Condition**	**Degree**
Green	Normal	<= 6.9
Yellow	Warning	7 – 9.9
Red	Alert	>= 10

7.1.6 Collection Requirements

ID: CR1

Title: UAS or Helicopter LiDAR Collection

Description: LiDAR data must be collected according to SDG&E specifications (see SDG&E Document TE-0135; Specification for Surveying, Aerial Photography and Mapping of Overhead Transmission and Distribution Line Corridor).

ID: CR2

Title: UAS or Helicopter Imagery Collection

Description: LiDAR data must be collected according to SDG&E specifications (see SDG&E Document TE-0135; Specification for Surveying, Aerial Photography and Mapping of Overhead Transmission and Distribution Line Corridor).

8.0 Project Outcome

In this section, recommendations and prospective next steps resulting from this EPIC project module are presented for the industry to consider.

8.1 Recommendations

8.1.1 General Recommendations

The recommendations outlined below are general recommendations that were discussed and presented by the Project Team to the stakeholders throughout the various project meetings.

Implementation of Data Standards

To guarantee the consistency and quality of data, SDG&E should develop and put into effect data standards to cover the collection, format and maintenance of all data types. Standards provide data integrity, accuracy and consistency and minimize redundant data. Utilizing high quality data allows organizations to make better business decisions and produces cost savings through increased productivity since staff will spend less time reconciling inaccurate and missing data.

Data Retention Policy

A retention policy should be created that considers all data types and data owners to ensure clarity in how long data and information should be retained.

Mobile Data Collection Tool

Currently, much of the field data is collected manually by means of handwritten notes then converted to electronic format on return to the office. The introduction of a mobile tool would streamline the data collection process, decrease loss of information risks, reduce duplication of effort, improve data consistency and provide near instantaneous data transmission.

The mobile data collection tool must have offline capability to allow data collection when there is no internet connection.

Voice Recognition Software

By introducing the capability to allow dictation from within the mobile tool, using voice recognition software, can dramatically increase productivity. Statistics show that productivity may be increased by up to three times in comparison to typing. This capability could be particularly useful when collecting field notes.

Collection of Cultural Imagery

The Environmental Services Cultural Team expressed imagery collected by UAVs must have sub-meter accuracy to realize the most benefits for them.

Field Training Programs

To maximize the value of time spent by employees in the field, SDG&E should consider running comprehensive training programs that cover in field data collection techniques, in field data analysis, equipment use and health and safety considerations.

Batch Uploads

CSV file templates must be developed for all batch upload scenarios. Ideally, one template should be created that can be used for all eventualities. It is important that all reports for batch upload contain GPS coordinates, so they can be georeferenced within the system.

Infrared and Ultraviolet Data

To inform accurate tree health estimates using advanced data analytics, SDG&E should consider collecting infrared and ultraviolet data in areas where tree health assessments must be made. IR and UV data is also critical for detecting hot spots, corona and partial discharge.

Tree Health Data

To ensure consistency, data related to tree health must be collected in a consistent manner and consideration should be given to the season in which the data is collected. Unhealthy and dead foliage can occur on healthy trees in the autumn and winter when the leaves are senescing. Thus, images collected too early in the spring or too late in the fall will produce spurious results.

Locations of Individual Trees

Vegetation Management would like access to a handheld device that can be used in the field to determine and collect the GPS locations of individual trees. The tree location data held in Powerworks is not as accurate as it could be and often trees are not displayed correctly because of grouping and stacking. There is potential to supplement aerial data with terrestrial scans and photogrammetry taken from below the canopy to assist with this.

8.1.2 Recommendations for Vendor-Agnostic System

The recommendations outlined below were discussed and presented by the EPIC Project Team to the stakeholders during the vendor demonstrations and apply to both vendor tools. The project team recommends commercial adoption of this technology for SDG&E.

Link to Customer Information

The vendor system should be integrated with a source of customer information to allow specific users to resolve customer centric concerns.

Stakeholder Group Dashboard

A dashboard should be created for each stakeholder group that contains key information and provides a quick view to overall asset health and recent updates.

User Defined View

A user should be able to create their own default view that allows them to select the layers, labels, zoom levels and other constraints that are most useful for their day to day business. User preferences could be stored within login information.

Current Aerial Imagery

SDG&E personnel must have access to current aerial imagery to conduct their initial desktop analyses accurately. The vendor system must be able to leverage up to date aerial imagery from an external source and present it in a useable format.

Tree Canopies

Ideally, an algorithm would be in place that could calculate the numbers of trees in each canopy and display them on the screen logically using marker clusters. As a user zooms into any of the cluster locations, the number on the cluster will decrease, and the user will begin to see the individual markers on the map. Zooming out of the map consolidates the markers into clusters again.

Retention Policy

A workflow must be implemented within the vendor system that reflects the retention policy and allows data to be flagged with the appropriate retention period on ingestion.

Data relevant to the construction and maintenance of an asset must be retained for the life of the asset plus five years. To accommodate this, a mechanism must be put in place to feed in construction decommissioning dates.

8.2 Next Steps

The internal EPIC Project Team and vendors have worked closely with SDG&E stakeholders to gather and execute on a variety of functional and implementation requirements, and a series of next steps has been jointly compiled. Key areas for consideration include:

Identify IT security and user access controls to maintain data security requirements

This critical topic was briefly discussed during project meetings, but there is much more detail required to implement a system that will provide the right level of access to each user while complying with organizational security requirements.

Determine specific requirements for integration with other operational systems such as GIS and work order management

While there is clearly value in a user interface to the system for data managers, analysts, and occasional users who have access to specific dashboards and reports, there are also valuable uses of the system as an integration point for downstream operational systems. There is a significant opportunity to leverage information from the vendor platforms throughout the enterprise by integrating with these operational systems.

Implement deep learning and other geospatial analytics to automate maintenance inspections, construction planning, vegetation management and other operational workflows

Several examples of automating workflows through analytics were demonstrated, but there are significant opportunities to expand the use of both vendor systems. Both vendor systems can be configured to handle many other workflows and analytics can be developed to support them.

Determine stakeholder requirements for user interfaces and dashboards to ensure analytic results are timely and meaningful

For those users who will be interfacing directly with the system, it will be critical to design ergonomic interfaces to allow easy use of the system. Data administrator, data analyst, inspector, and engineer are a few of the user personas that should be formally implemented.

Ensure UAS imagery and LiDAR is collected to realize the most benefits to stakeholders by informing deep learning and other advanced data analytics

The UAS should be flown in close proximity to the poles to collect imagery and LiDAR data that will be suitable to identify hardware and the firebreaks. Enough data must be collected to allow for an additional training set to train any deep learning tool. Larger datasets available for training result in more accurate and reliable results.

Data collection should be expanded outside of pole corridors to cover surrounding areas. This would inform several key use cases for the Environmental Services team, including the identification of potential pole sites, the identification of staging yards and comparison of pre- and post-construction sites.

Collect more of the same data to allow comparative works to be undertaken to detect changes in the infrastructure and landscape over time.

Expand pole accessibility test case to determine the best route to the pole

Both vendors successfully quantified the straight-line distance and terrain type from the roadway to a pole. This test case be expanded to produce route options to reach the pole where the maximum gradient, proposed vehicle type or on foot, and obstructions, such as canyons, are considered.

9.0 Technology Transfer Plan

9.1 SDG&E Technology Transfer Plan for Project Results

A primary benefit of the EPIC program is the technology and knowledge sharing that occurs both internally within SDG&E and across the industry. To facilitate this knowledge sharing, SDG&E will share the results of this project by widely announcing to industry stakeholders that this report is available on the SDG&E EPIC website and by presentations in EPIC and other industry workshops and forums. SDG&E will also conduct formal presentations of the results to internal stakeholders to encourage adoption, as needed.

9.2 Applicability to Other Utilities and Industry

As technology evolves, utilities are poised to leverage UAS and other data collection technologies to capture high resolution imagery and increase visualization and situational awareness for operations. In some cases, these images have been stored and used by individual stakeholders in different business units within the organizations for their own purposes. This EPIC project module demonstrated the value of having a central repository (data management platform) to store, catalog, and sort data that could be visualized by multiple stakeholders concurrently. It allows the stakeholders to create custom views for their area of operations. It also allows the stakeholders to perform deep learning analytics on the vast amount of data to provide actionable results for applications ranging from automated identification of equipment on poles to tracking vegetation encroachment on power lines. These are just a few of the use cases that the data captured from UAS will enable stakeholders to leverage. All these cases will enable the utilities to perform virtual asset inspection that enhances safety and reliability of power system equipment.

10.0 Metrics and Value Proposition

10.1 Metrics

This project module used various demonstrations to evaluate and measure the value of UAS technology and advanced data analytics tools, provided by vendors. In addition to results from the test cases, the following metrics should be considered by users when assessing the project outcome and/or using the project results:

Maintain/reduce operations and maintenance costs

The project successfully demonstrated how implementing a single centralized repository, UAS for data collection and advanced data analytics can be used to reduce inefficiencies, increase productivity and reduce operations and maintenance costs.

Implementation of a central repository will prevent duplication of effort by preventing teams from inspecting or surveying areas that have already been recently inspected, improve decision making, and result in overall cost savings for SDG&E.

Sending out staff to manually conduct inspections and auditing tasks is extremely time, labor and resource intensive and there are many associated safety and accessibility issues. Collecting and assessing UAS data as a pre-condition to conducting a physical inspection allows the inspection to become much more focused. Having up-to-date UAS imagery can greatly improve inspection planning, reduce the number of hours needed for the inspections, and free up resources to work on other tasks, ultimately resulting in cost savings for SDG&E.

Finally, the implementation of advanced data analytics, to automatically identify areas of interest, for example poles that are leaning, significantly reduces the time, cost and effort required to go into the field and physically inspect each pole. Advanced data analytics can be used to improve day-to-day business processes and realize efficiency savings in a vast number of areas. Key areas where advanced data analytics can be utilized within the industry include planning and forecasting, change detection, feature identification and auditing.

Habitat area disturbance reductions

Not only is the use of UAS more cost effective than most other data collection methods, it is also much more beneficial for the environment. UAS can be sent out quickly and easily to conduct aerial inspections and surveys, while generating minimal disturbance and noise to the surrounding wildlife and habitat. By eliminating the need to have "feet on the ground", plants and wildlife are not affected by humans conducting physical inspections.

Utility worker safety improvement and hazard exposure reduction

Using UAS to collect data significantly improves the safety of utility personnel by reducing the need for manual data collection inspections. UAS has a unique ability to inspect difficult to reach and hazardous areas, meaning that personnel do not have to put themselves in danger by attempting to reach these places. Advanced data analytics is also used to provide data metrics about the health of the infrastructure and surrounding environment, which in turn lessens the amount of field work that is required.

10.2 Value Proposition

The purpose of EPIC funding is to support investments in R&D projects that benefit electric utility customers. The utility EPIC activities are limited by the EPIC ordering decisions to precommercial demonstrations of technologies and integration solutions that provide benefits to customers by promoting greater reliability, lower costs, increased safety, and other designated benefits. This EPIC project contributes to these benefits in the following ways:

Safety

The use of UAS technology enables remote asset management and keeps utility personnel away from hazardous and dangerous terrain. In addition, advanced data analytics lessens the amount of field work needed to identify change, features and equipment within the network area. During emergencies, such as wildfires or other natural disasters, UAS technology can act as a first line of defense in monitoring and tracking the situation remotely, therefore ensuring the safety of personnel and limiting harm to people and property.

Reliability

When collected frequently, UAS data can improve the reliability and accuracy of system data. Having current data is essential in the decision-making process and allows personnel to make business decisions that are reliable and supported. Advanced data analytics can be used to identify issues before they become critical and allows stakeholders to take mitigating action at an earlier stage. This improved ability to plan and predict, in turn increases the reliability of the service offered.

Efficient use of ratepayer monies

The technologies and tools demonstrated in this project significantly reduce the number of physical inspections that need to be conducted. Inspection crews can be deployed more effectively, with a more focused remit, which reduces the time, resources and costs involved, thereby making efficient use of ratepayer monies.

Environmental benefits

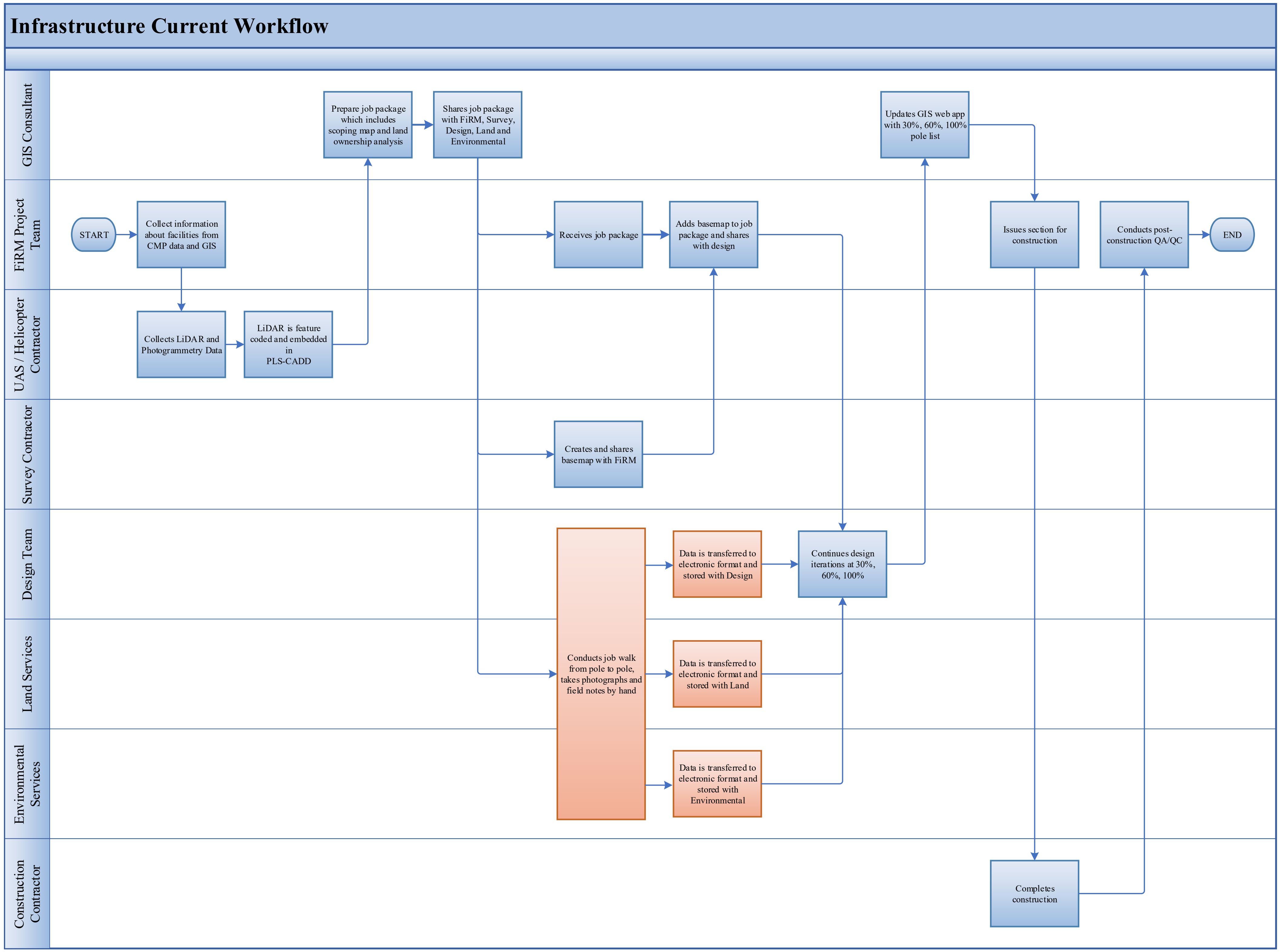
The technologies and tools demonstrated in this project will benefit the environment by reducing the amount of physical activity in remote areas and the resulting disturbance to flora and fauna. The demonstrated solutions will also become part of a larger capability to fight wildfires, vegetation diseases, and other major disasters which would damage the environment.

Barriers and issues resolved that prevented widespread deployment of technology or strategy

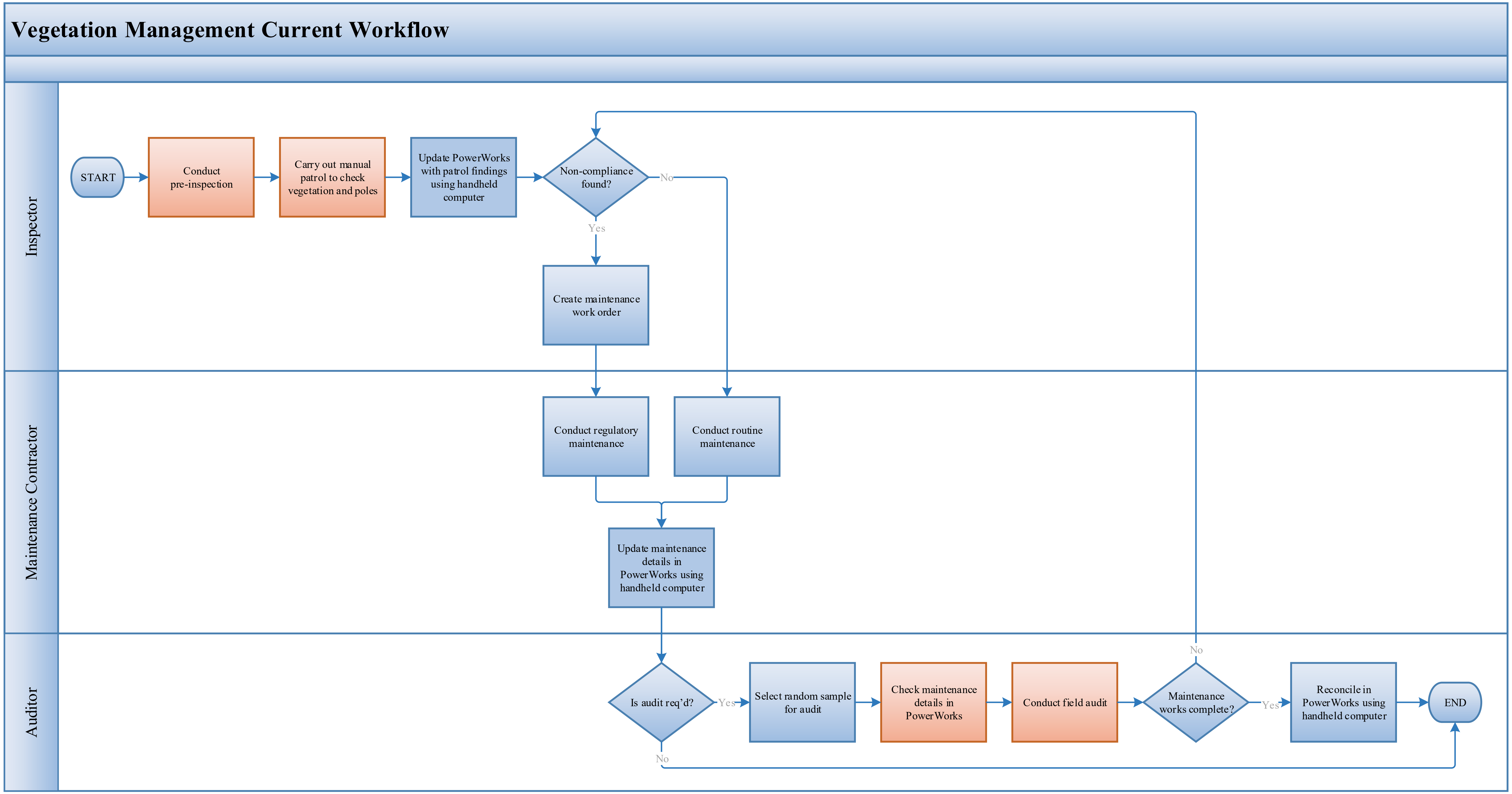
The demonstration work performed in this project confirmed that a major issue that needs to be resolved to enable more widespread use of UAS is improvement of the data handling capabilities. The needed capabilities include an efficient central data repository and better tools for analyzing the data for application in solving specific engineering and operations problems. The demonstration work evaluated specific concepts to aid in decisions on commercial choices for large-scale use. But, more work is needed by the industry to develop better tools.

11.0 Appendices

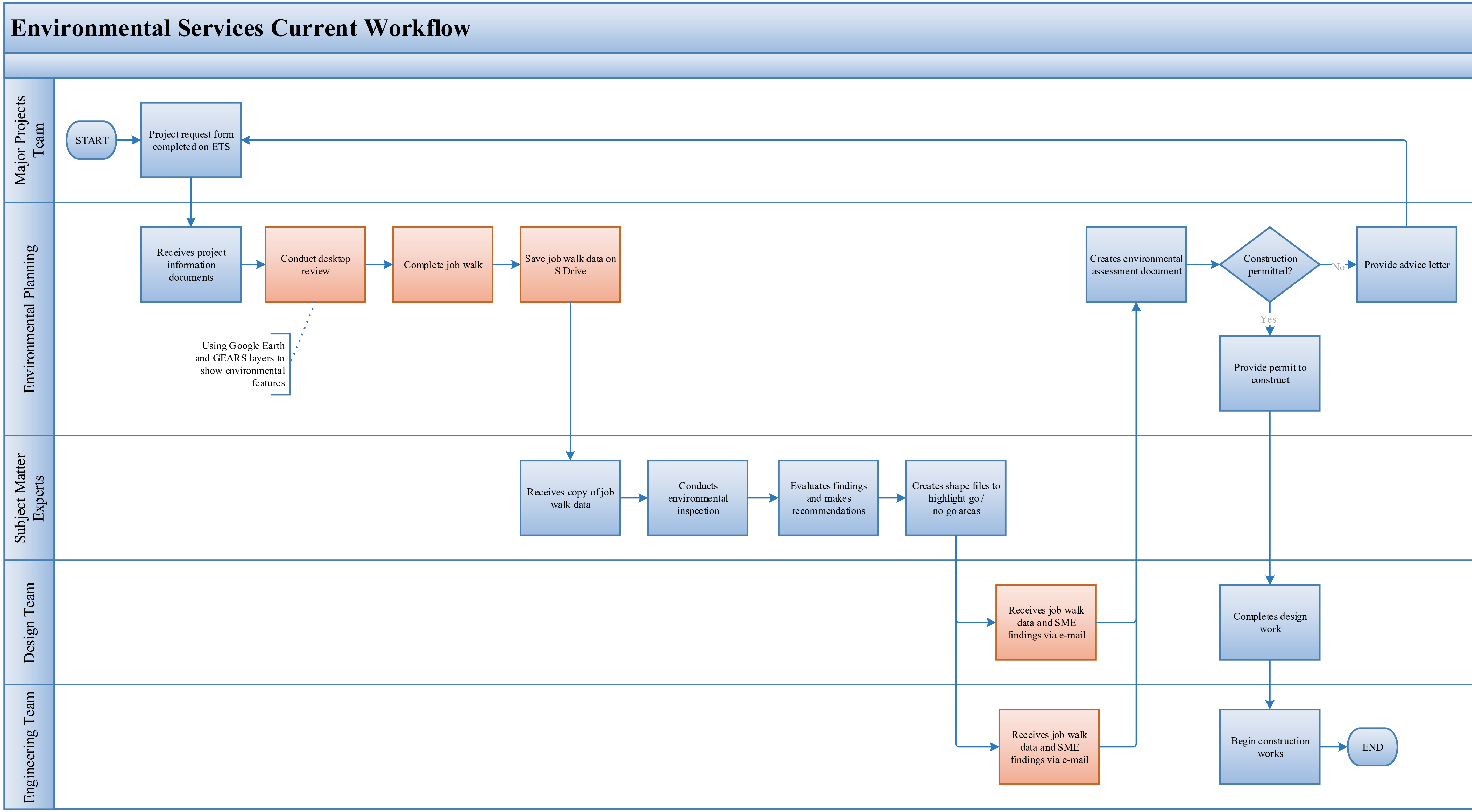
11.1 Appendix A – Infrastructure Current Workflow



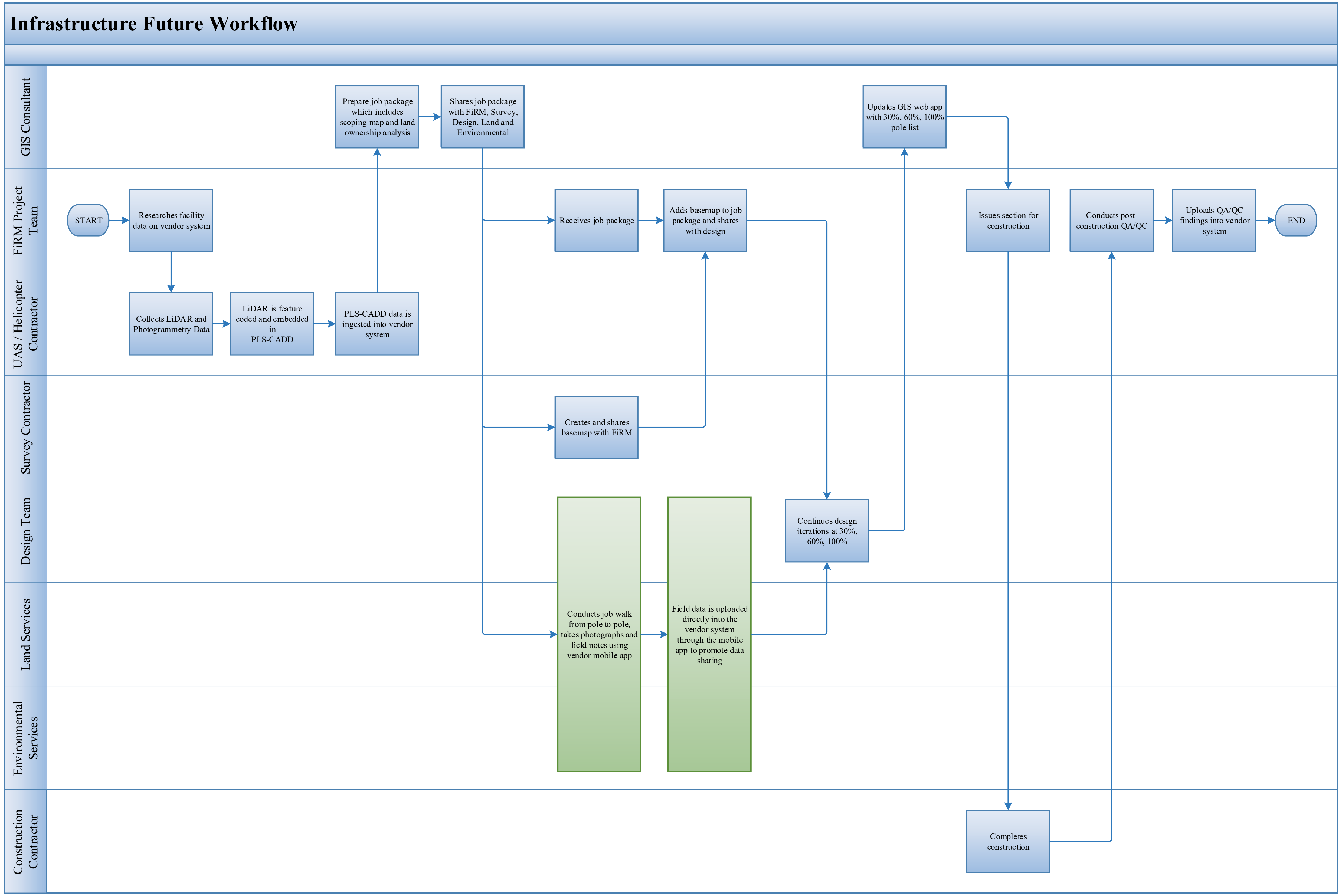
11.2 Appendix B – Vegetation Management Current Workflow



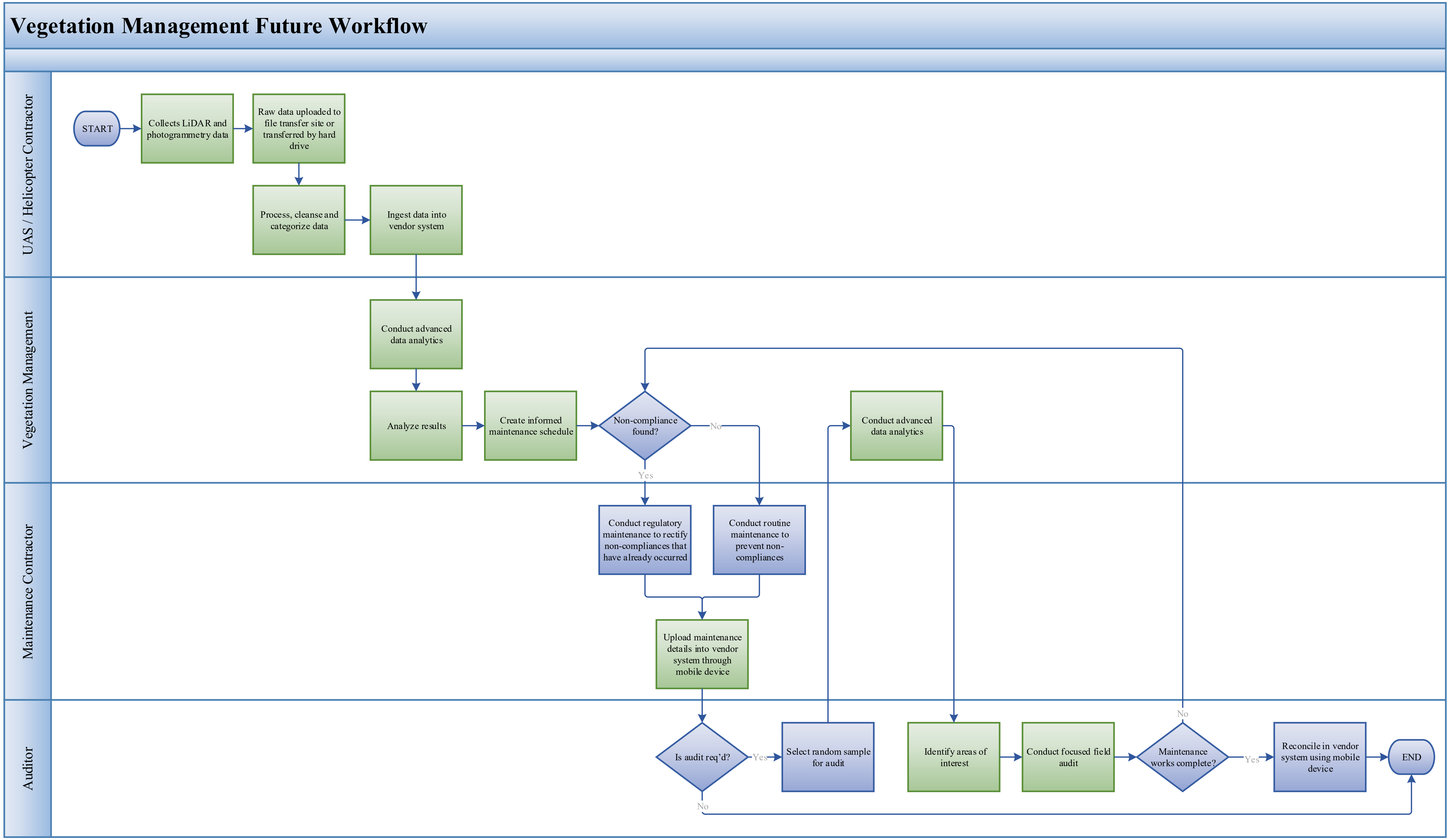
11.3 Appendix C – Environmental Services Current Workflow



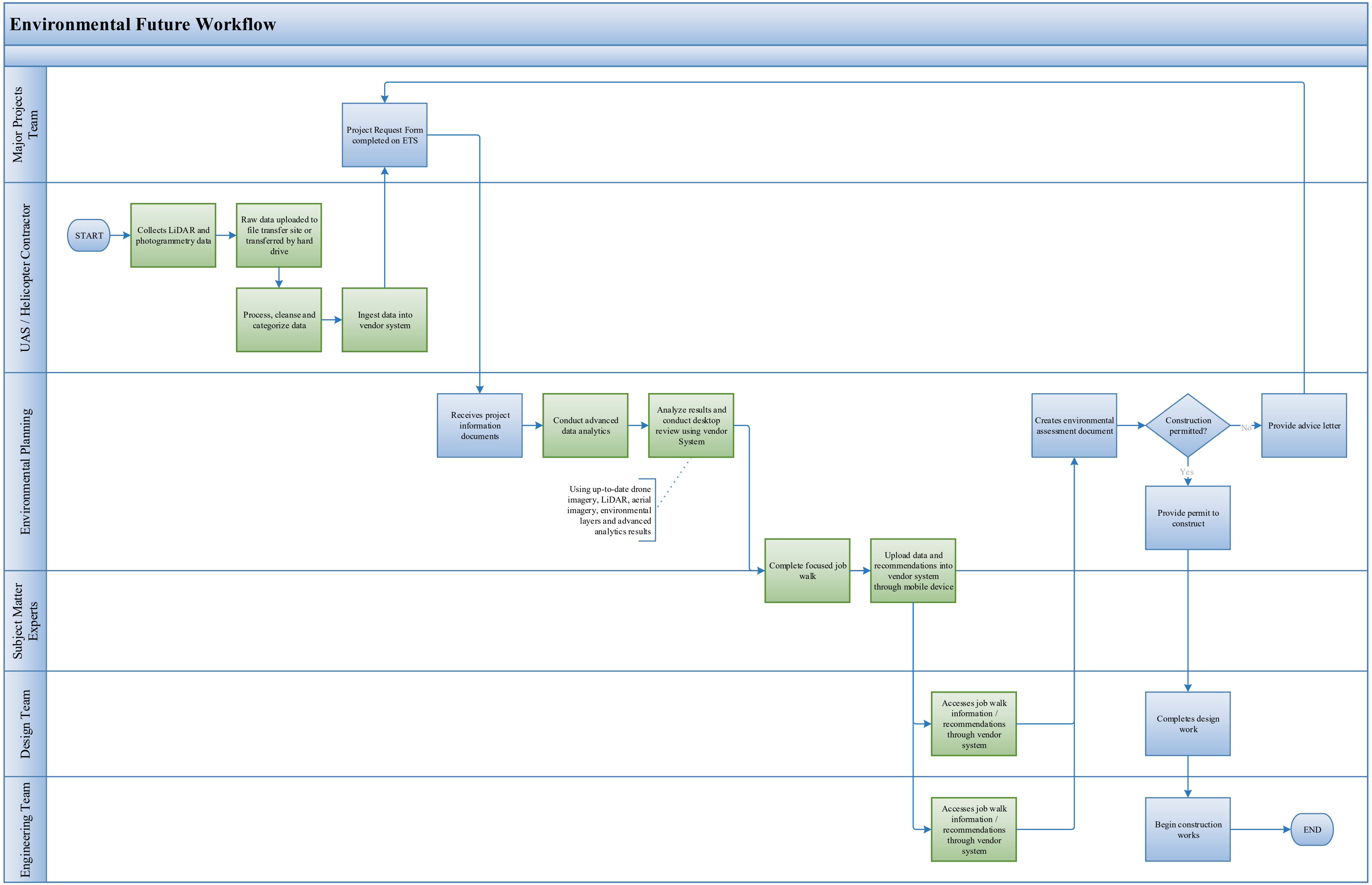
11.4 Appendix D - Infrastructure Future Workflow



11.5 Appendix E - Vegetation Management Future Workflow



11.6 Appendix F – Environmental Services Future Workflow



11.7 Appendix G – Vendor / Stakeholder Use Case Matrix

Vendor A	Vendor B	Stakeholder Use Cases	
		3.1.1 – Data Collection	**Infrastructure**
X	X	3.1.2 – Data Ingestion	
X		3.1.3 – Data Storage	
X		3.1.4 – Data Visualization	
X		3.1.5 – Data Retention	
X		3.1.6 – Data Removal	
		3.2.1 – Identifying Hardware and Firebreaks	**Vegetation Management**
X		3.2.2 – Identifying Tree Growth Patterns	
X		3.2.3 – Identifying Areas of Tree Health	
X	X	3.2.4 - Identifying Changes in Pole Lean	
	X	3.2.5 - Maintenance Audit	
		3.3.1 - Identification of Potential Pole Sites	**Environmental**
	X	3.3.2 - Identification of Water Bodies	
		3.3.3 - Identification of Vegetation Community	
		3.3.4 - Identification of Birds' Nests in Vegetation	
		3.3.5 - Identification of Noxious Weeds and Invasive Species	
		3.3.6 - Identification of Staging Yards	
		3.3.7 - Comparison of Pre- and Post-Construction Work Areas	
X	X	3.3.8 - Pole Accessibility from Road	
X		3.3.9 – Capture of Pole Accessibility Field Notes	

Common use cases between stakeholders are shown in red.