A Sempra Energy utility

EPIC Final Report

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Administrator	**San Diego Gas & Electric Company**
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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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Executive Summary

The objective of EPIC-2, Project 6 (Collaborative Programs in RD&D Consortia) is to accomplish highly leveraged demonstration work through industry collaborative R&D organizations. 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 team 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 vendor determined zone(s) around electrical wires which provided a road map for future proactive vegetation maintenance efforts. The project's findings suggested potential Imagery Data Management Platforms (IDMP) which would improve current asset management and data lifecycle management processes, producing a roadmap that would enable integration of the technology used by each vendor.

Unmanned Aerial Systems (UAS) have provided a unique opportunity for SDG&E to obtain, disseminate and use aerial sensor data that provides benefits such as cost savings to its ratepayers and lower physical risks to SDG&E personnel while increasing public safety. The primary project objective was to demonstrate platforms that could integrate 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 GIS, PLS-CADD, UAS collected data and other various sources.

The project scope included identification of the vendors' proposed IDMP and demonstration of their tool's Data Lifecycle Management (DLM) workflow process and how it integrates with existing and future SDG&E platforms. The vendors approach was based on stakeholders' current workflows and data requirements. The test segment consisted of a SDG&E 1.25-mile segment of a distribution circuit that included 30 electrical distribution poles. The test segment was selected due to previous LiDAR data collection as part of the Fire Risk Management (FiRM) program and provided an accurate representation of minimally accessible terrain.

The three test cases identified for the project addressed Proof of Concept (POC) on the following:

1. *Avian Cover Identification* – Test case to evaluate the identification of assets (avian cover) through advanced analytics on RGB images and demonstrate value for continual maintenance and visual inspection.

2. *Vegetation Encroachment Identification* – Test case to evaluate identification of vegetation encroachment within a buffer zone around power lines, thereby assisting in identification of trees for maintenance and trimming.
3. *Cataloging and Remote Asset Management* – Test case to demonstrate ingestion of data from various data sources and cataloging metadata information of existing assets that enables remote visualization and management of assets.

The results of the three test cases were presented and demonstrated to SDG&E stakeholders to give them the ability to examine and compare the vendors' tools for usability and functionality. None of the vendor tools were developed to a point where they could be integrated without modification to current SDG&E systems, but the POC's were clearly demonstrated by all vendors.

The EPIC project was successful in demonstrating the ability of vendors to utilize tools that ingested existing, new operational, and inspection data sets to perform analysis on spatial data and metadata to be viewed by users on a cloud-based platform. Assets were viewed remotely with attached metadata for analysis and measurement in a 3-dimensional environment. Machine learning was used to analyze LiDAR and imagery data for automated identification of encroaching vegetation and avian covers. It was also clearly identified there would be an immediate increase in efficiencies and utilization by providing access to data sets currently collected and analyzed by individual stakeholders. Efficiency would also increase by providing LiDAR, imagery and other UAS data collected during design and as-built phases of engineering to other stakeholders or a data management tool for analysis and inspection.

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. The evaluation should also focus on developing requirements for integration of this data management platform into the SDG&E information technology environment. While the project successfully demonstrated the value of advanced analytics using UAS data, additional evaluation is required before operational deployment of the data management platform.

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Abbreviations & Acronyms

Acronym	***Definition***
AI	Artificial Intelligence
AOM	Aviation Operations Manual
API	Application Programming Interface
APM	Asset Performance Monitoring
ASD	Aviation Services Department
BAK	Backup File
BOM	Bill of Material
CAD	Computer Aided Design
CAPP	Computer Aided Process Planning
CIP	Critical Infrastructure Protection
CR	Change Request
DLM	Data Lifecycle Management
DMP	Data Management Platform
DSM	Digital Surface Model
DTM	Digital Terrain Model
DXF	Drawing Exchange Format
EAM	Enterprise Asset Management
EPIC	Electric Program Investment Charge
ERP	Enterprise Resource Planning
Esri	Environmental Systems Research Institute
FAA	Federal Aviation Administration
FiRM	Fire Risk Management
FMV	Full Motion Video
FTP	File Transfer Protocol
GIS	Geographic Information System
GPS	Global Positioning System
IDMP	Image Data Management Platform
IR	Infrared
IT	Information Technology
KML	Keyhole Markup Language
KMZ	Keyhole Markup language Zipped
LAS	Log ASCII Standard

LDAP	Lightweight Directory Access Protocol
LiDAR	Light Imaging Detection and Ranging
NCR	Non-Conformance Report
NERC	North American Electric Reliability Corporation
OGC	Open Geospatial Consortium
PLM	Product Life Cycle Management
PLS-CADD	Power Line Systems - Computer Aided Design and Drafting
POC	Proof of Concept
PPK	Post Processed Kinematic
PS	Part Shortage
PSEP	Pipeline Safety Enhancement Plan
QR	Quality Report
RACI	Responsible, Accountable, Consulted, Informed
RBAC	Role Based Access Control
RD&D	Research, Demonstration and Deployment
RGB	Red, Green, Blue
RoW	Right-of-Way
RTK	Radio To Kinetic
SDG&E	San Diego Gas & Electric
SHP	Shape file
SMS	Safety Management System
SN	Serial Number
SOP	Standard Operating Procedures
SPARC	SDG&E Portal for Awareness and Real-time Collaboration
SRTM	Shuttle Radar Topography Mission
SQL	Sequential Query Language
TIFF	Tag Image File Format
TL	Transmission Line
T&D	Transmission and Distribution
UAS	Unmanned Aerial Systems
UAV	Unmanned Aerial Vehicle
UV	Ultraviolet
WCS	Web Coverage Service
WFS	Web Feature Service
WMS	Web Map Service

1.0 Introduction

1.1 Project Objective

The objective of EPIC-2, Project 6 (Collaborative Programs in RD&D Consortia) is to accomplish highly leveraged demonstration work through industry collaborative R&D organizations. The focus of this project module on Unmanned Aerial Systems (UAS) Data Lifecycle Management and Deep Learning Demonstration was to demonstrate cloud-based platforms that could integrate with existing and future San Diego Gas and Electric (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 Design and Drafting (PLS-CADD), UAS-collected data, and various other sources. The purpose for the research was to assist in identifying potential uses for the data among stakeholders. The goal was to determine an appropriate data lifecycle management plan that benefits most stakeholders and incorporates planning, design, construction and maintenance.

Other goals included process improvements in UAS data collection and insight into standardized requirements based on usage and tool criteria. SDG&E also desired a plan for integration with Environmental Systems Research Institute (Esri) GIS and PLS-CADD programs, along with legacy stakeholder platforms such as PowerWorkz and the SDG&E Portal for Awareness and Real-time Collaboration (SPARC) used by Vegetation Management and GIS. In this project module, SDG&E aimed to provide the Proof of Concept (POC) that machine learning tools have the ability to ingest various data sets and perform tasks such as asset identification through image analysis and spatial proximity determined by analysis of Light Imaging Detection and Ranging (LiDAR), and imagery or full motion video.

The end goal was to identify process improvements creating a more reliable network with increased safety and lower risk, while lowering overall operational costs and passing these savings on to customers.

1.2 Issue/Problem Being Addressed

SDG&E currently collects LiDAR, Red, Green, Blue (RGB) video and imagery, Infrared (IR) and Ultraviolet (UV) data for the company's electrical system each year, for a multitude of business cases. All aerial data collection is coordinated through the Aviation Services Department (ASD) group. Data is collected for distribution and transmission line design, as-built, line/assets inspection, marketing, sales and operational efforts. The UAS imagery data is subsequently provided directly back to the requesting stakeholder without the capabilities for dissemination to other potential end users.

The current workflow has resulted in large collections of useable data being stored on individual department's storage drive, not accessible by other stakeholders within SDG&E. Storage drives are managed by permission only to individual personnel within each department thus preventing other groups from accessing data and duplicating the information in storage. There is currently no IDMP in place to link all the storage drives, enrich data with other attribute information, manage the lifecycle of data or become accessible by others within the company. Resulting silos of data sources and the high-level assessment of ASD operations are described and diagramed in more detail in Section 2.0 below.

The standardized collection and dissemination of data sets have the potential to provide substantial increases in productivity and efficiency throughout SDG&E, resulting in an overall decrease in total cost to ratepayers. Increased sharing of data through an Image Data Management Platform (IDMP) available to all company groups would mitigate safety concerns for personnel accessing remote assets or difficult access issues where SDG&E is unsuccessful in gaining entrance. It would also allow stakeholders with limited staff resources to focus their efforts through automated identification and reporting of an assets' status or location based on specified criteria or thresholds.

1.3 Project Task Summary

The project was implemented in three phases:

- Phase 1 – SDG&E Internal Project Work Prior to contractor procurement that includes
    - Task 1: Development of Project Plan
    - Task 2: Contractor Procurement
- Phase 2 – Project Development Activities
    - Task 3: Baseline Analysis (Evaluate existing infrastructure)
    - Task 4: Requirements Elicitation and Design
    - Task 5: Test System Setup and Integration
    - Task 6: Demonstrate Data Lifecycle Management
    - Task 7: Display Vendor Tools with GIS and PLS-CADD
    - Task 8: Advanced Analytics Demonstration
- Phase 3 – SDG&E Internal Project Work prior to project conclusion
    - Task 9: Finalize Project Report for External Release
    - Task 10: Technology Transfer Plan

A summary of each of the tasks performed during the execution of the project follows. Each of the tasks were performed with direction and input from representatives of each of the participating stakeholder groups described in Section 2.2 below. SDG&E engaged four vendors to utilize their data management platforms to undertake pre-commercial demonstration of the test cases. Due to time constraints, not all the tasks were performed by all vendors, though the POC for the test cases described in Section 3.2 below were demonstrated by each vendor.

1.3.1 Phase 1 – SDG&E Internal Project Work Prior to Contractor Procurement

Task 1 – Development of Project Plan

Objective – Develop detailed work plan for the project.

Approach – The project team met with SDG&E stakeholders to conduct a review of existing processes of data capture from UAS and other applications of data capture. The project team identified conceptual vision for the proposed test platform that could demonstrate multiple use cases leveraging UAS data analytics. The project plan identified staffing requirements for the project, both internal and contracted, with definition of needed skills. Required equipment and other resources were also identified,

Output - Project work plan including technical scope definition, schedule, budget, and staffing requirements was developed

Task 2 – Contractor Procurement
Objective – Procurement of contractor services under contract with Supply Management.

Approach – The project team engaged with a set of contractors. The selected contractors had data management platforms that were uniquely qualified to demonstrate the test cases that were envisioned in the conceptual vision for the proposed test platform. The objective was to leverage multiple vendor platforms in a collaborative manner that would help SDG&E determine the requirements for a UAS data management platform under various operational and business scenarios. The following documents were developed and finalized as part of the contracts package for the four vendors that were selected.

- Detailed scope of work
- Detailed project schedule
- Detailed Project Budget
- Professional services agreement

Output – Contract agreements were finalized with SDG&E supply management and four UAS platform providers that are referenced in the attribution page upfront in the document. A fifth contractor was selected to perform engineering services for the project team to achieve the desired project objectives.

1.3.2 Phase 2 – Project Development Activities

Task 3: Baseline Analysis (Evaluate existing infrastructure)
Objective –Identify existing infrastructure for data collection, storage and dissemination.

Approach – The project team met with SDG&E stakeholders to identify existing and potential UAS workflows and data requirements. Current practices related to flight planning, contractor vetting, quality control, data management and other aviation services functional operations were assessed to make recommendations for areas of improvement.

Output - A 1.25-mile segment of circuit containing 30 poles was selected for analysis on this project and the baseline data set was developed for testing purposes.

Task 4: Requirements Elicitation and Design
Objective – The objective of this task was to develop requirements and design the ingestion of the data provided in the baseline data set or collected independently into a data management platform.

Approach – The project team met with SDG&E stakeholders to assess the requirements for data usage and ingestion for the use cases. These use cases are described in detail, by applicable stakeholder, in Section 2.2 below. Through various meetings, various processes were identified in collection requirements, technological limitations and data overlap between stakeholders.

Output – Test cases were developed from the previously identified use cases using the respondent stakeholders input regarding the possibilities of substantial impact to SDG&E stakeholders, potential benefit to ratepayers and the feasibility of completion within the short duration of the project. A test plan was developed independently by vendors for each test case. The results for test cases are described in further detail in Section 3.2 below.

Task 5: Test System Setup and Integration
Objective – The project team ingested new and existing data sources including still imagery, full motion video, LiDAR, along with other design and inspection data to a replicated IDMP for analysis by various tools.

Approach – Data sources were organized, cataloged and data reported from various data sources such as (but not limited to) LiDAR, RGB imagery with Global Positioning System (GPS) metadata and SDG&E GIS records to organize and catalog assets with minimal human interaction. They were also asked to demonstrate the ability to reconcile records from different data sources on the same asset and report any discrepancies back to SDG&E's GIS group to allow for database corrections. This task also included installing, configuring and testing tools after the ingestion and analysis of the provided data sets.

Output – The project team setup the various tools and integrated the dataset into the test system.

Task 6: Demonstrate Data Lifecycle Management
Objective –Demonstrate the lifecycle of the data within the tools using automated data lifecycle workflow to manage/purge/archive data according to stakeholder defined policies and SDG&E Information Technology (IT) Security protocols.

Approach – The test system was demonstrated with functionality using a web browser or thin user client for SDG&E stakeholders and the EPIC 2 Project #6 Team. A live session demonstration was provided by vendors to stakeholders for end users to gain experience with the vendor tool and proposed test cases. Lightweight documentation specific to test/use cases, functionalities, workflows and datatypes were created by vendors and delivered to SDG&E.

Output – The results for data lifecycle management are described in further detail in Section 3.2.5 below.

Task 7: Display Vendor Tools with GIS and PLS-CADD
Objective – Develop a plan to integrate vendor tools with GIS and PLS-CADD..

Approach – The vendors were requested to provide a plan for integration of their tools with GIS that captures the technology, business practices, and configurations required for future integration. Vendors were also requested to provide a workflow or show the ability to display LiDAR data and other PLS-CADD design components in their respective tools, and provide a method for query and/or download if possible. All vendors cataloged and ingested various GIS data sets and display them within their tools. Vendor B, Vendor C and Vendor D ingested PLS-CADD exports for visualization in their respective tools. Vendor C demonstrated the ability to export PLS-CADD specifications and 3D models for visualization and analysis in Vendor C Tool.

Output – The results for GIS and PLS-CADD integration are described in further detail in Section 3.2.4 below.

Task 8: Advanced Analytics Demonstration
Objective – Demonstrate deep learning analytics using UAS collected imagery and LiDAR data sets.

Approach – The project team demonstrated avian cover identification and the level of confidence for each identification. Demonstrated the ability to automatically detect vegetation within a specified encroachment zone to facilitate focused and proactive vegetation management.

Output – The results of avian cover detection are described in further detail in Section 3.2.1 below and the results of vegetation encroachment identification are described in further detail in Section 3.2.2 below

1.3.3 Phase 3 – SDG&E Internal Project Work prior to project conclusion

Task 9: Comprehensive Final Report
Objective – Develop comprehensive final report

Approach - A final report will be written to align with a final report outline developed by the project team at the start of the project. The outline should not conflict with the guidelines for final reports developed by the utility administrators of EPIC, but it should be more complete and follow a storyline of what occurs sequentially in the project. It should be prepared as a draft in MS Word for review and comments and a revision into final form, based on comments received on the draft. The final report is the crucial documentation of the project work, needed to assure that the information developed in the project does not get lost and is available to prospective users.

Output - Comprehensive final report as presented in this document

Task 10: Technology Transfer Plan
Objective – Develop technology transfer plan to share results with all stakeholders

Approach - A technology transfer plan was developed to share the results with SDG&E stakeholders and with other stakeholders in the industry that would benefit from this pre-commercial demonstration

Output - Technology transfer plan as documented in Section 5 of this report

2.0 ASD Operations Assessment

The ASD within SDG&E manages all aviation operations. They are responsible for coordination of flights for manned aircraft, UAS operations, updating SDG&E's Aviation Operations Manual (AOM), and vetting contractors using Unmanned Aerial Vehicles (UAVs) for data collection efforts. ASD is continually looking for process improvements to increase efficiencies and safety. Vendors were requested to evaluate current ASD operations and provide input to guide aerial data governance as well as overall processes and procedures.[1]

2.1 ASD Operations Summary

SDG&E's ASD currently handles all requests for UAS data from the stakeholders. ASD currently staffs 7 people that handle UAS operations. ASD informs stakeholders that UAS services are available through an internal bi-monthly newsletter that is distributed to all stakeholders. Stakeholders request data from ASD through request via SDG&E web portal or the "Aviation In-Box", which is an e-mail address that ASD has set up specifically for incoming requests. The current ASD workflow is summarized in *Appendix A: Aviation Services Department.*

[1] Portions of Section 2 were developed and/or quoted directly from vendor presentation or reports given to the EPIC-2 Project #6 team.

ASD provides support to all SDG&E stakeholders and performs UAS and helicopter aerial data collection for the specific needs of a project. Table 1 contains a sample of services that ASD has provided via UAS, manned aircraft and contractors:

Table 1. ASD Services

ASD Services		
Contractor Vetting	Line Inspection	QC Inspection of Pole Tension
Dam Inspection	Overhead Patrols	Structure Assessment
Demo Flights	Photo/Video for Marketing	UAS Training Flights
Flight Demos for Public Affairs	Photo/Video of Security Gates	Video of Gas Valve Restoration for Pipeline Safety Enhancement Plan (PSEP)
Imagery for Preconstruction	Photos of High Voltage Signs	Video of Mission Control Fence Lines
Inspection of High Pressure Gas Line	Photos/Videos	Video of TL on CNF
Landscape Projects	Pole Assessment	Yard Inspection

The services ASD provides to stakeholders and their use of the data varies greatly. Table 2 depicts the different types of data utilized by stakeholders that requested data from the ASD at the time of this project.

Table 2. Data Utilization by Stakeholders

Stakeholder	RGB Imagery	RGB Video	LiDAR	Infrared	Ultraviolet	PLS-CADD
Transmission/Distribution Maintenance	X	X		X		
Transmission/Distribution Engineering	X	X	X			X
Electric Standards	X	X				
Environmental	X	X				
Emergency Services	X	X				
Facilities	X	X		X		
Legal	X	X				
Construction Supervisors	X	X				
Media & Public Relations	X	X		X		
Vegetation Management	X	X				

After the review of incoming requests from stakeholders, the decision is made whether data acquisition would be better handled by ASD or a contractor primarily based on scope, schedule, data type, equipment and available personnel requirements. If it is determined that the data acquisition should be executed by ASD further review is initiated to determine the appropriate method for data collection, UAS or helicopter. If the data is being acquired by a contractor, the appropriate vendor is selected based on sensor requirements and availability. The following table shows the types of sensors available from ASD and SDG&E UAS contractors:

Table 3. Sensors from ASD and SDG&E UAS Contractors

	RGB Imagery	RGB Video	LiDAR	Infrared	Ultraviolet
SDG&E Aviation Services Department	X	X	X	X	
AES	X	X			
Burns & McDonnell	X	X			
Flight Evolved	X	X	X	X	
Skyscene	X	X	X	X	
Unmanned Aerial	X	X		X	
WH Pacific	X	X			
Birdseye Aerial	X	X		X	

UAS data collected with these types of sensors has many potential uses for various stakeholders. Some of the additional applications identified by the ASD group and vendors which were not tested during this project are described as follows:

- 3D pole modeling for structural alignment providing the added benefit of pole integrity risk management.
- Thermal Scanning would be beneficial for component and line assessments. Thermal scanning can provide identification of hot spots and this process has the potential of being automated utilizing machine learning.
- Corona Scanning can provide condition assessments on SDG&E facility components for early identification of failing components to provide proactive mitigation of risks.
- Emergency Planning & Response, UAS has the unique ability to access areas that would be hazardous for personnel to enter. UAS can give a “bird’s eye” view of terrain

enabling enhanced planning, management and decision making.

2.1.1 ASD UAS Data Collection

If UAS is found to be best suited for the stakeholder data acquisition, ASD begins a risk assessment by accessing available data on the internet using resources like “Google Earth”. While performing the risk assessment ASD looks for things like schools, livestock, homes, etc. ASD also checks to ensure that the flight will be compliant with current Federal Aviation Administration (FAA) regulations for the area where they are anticipating data collection via UAS. ASD has waivers in place through the FAA to remain in compliance with Part 107 of Federal Regulations when flying in controlled airspaces. Homeowners that have property that fall within the flight path of the UAS are given notice using the existing SDG&E Public Outreach phone system. If these factors cannot be safely mitigated, the flight will be postponed, and the request is declined. Mobilization from the ASD is achieved within hours of receipt of stakeholder request. On-site the ASD UAS team goes through pre-flight checklists to ensure safety, review scope, perform hazard analysis, etc. The UAV is flown by an FAA Part 107 Certified Remote Pilot and the data is collected. ASD has provided RGB photos and videos to stakeholders using this process.

Data is collected and processed by ASD. Once processed the data is delivered via thumb drive or email directly to the stakeholder. The data is also stored on an ASD laptop computer which is currently not accessible to other SDG&E stakeholders.

2.1.2 Contractor UAS Data Collection

Contractors provide various data sets including RGB imagery, LiDAR, IR, UV and PLS-CADD files as needed by requests from stakeholders via ASD request process. Contractors are also required to be vetted by ASD which is executed in three phases:

2.1.2.1 Phase 1 - Documentation:

ASD personnel distributes to potential contractors a packet indicating the necessary documentation to proceed in the vetting process. This information is to be completed and sent back to the ASD via email as the first step in becoming a ASD approved vendor for SDG&E.

Contractors must provide the following documentation to ASD:

- FAA Part 107 Certificate (or Part 61 if operating under a Section 333 exemption)
- Certificate of Insurance for $10M
- Type of UAS to be flown
- Logbook/Pilot Resume/Experience flying for utilities
- Proof of FAA registration

<u>If available, provide the following documents</u>

- Checklists
- Safety Management System manual

- Maintenance practices
- Risk assessment worksheet

2.1.2.2 Phase 2 – In-person Interview:

Meet with vendor to introduce/review the following:

- SDG&E AOM
- SDG&E Safety Policy
- Risk Assessment
- TracPlus and flight following procedures
- Contractor notification form

2.1.2.3 Phase 3 – Flight Operations:

Vetting Flight - After a vendor is approved to provide UAS services for ASD, they must submit their flight plan to ASD before executing any UAS mission. Upon approval the vendor mobilizes, follows pre-flight procedures for safety and accuracy, acquires and processes the data. Data is delivered directly to the stakeholder in this workflow as well.

SDG&E solicited its stakeholders to gauge interest in UAS data collection services and they were informed that the focus of this project would be on UAS and field data collection in the areas shown in table 4 below:

Table 4. Potential Applications for UAS Data

Potential Applications for UAS Data		
Construction and Maintenance	Fire Risk Mitigation	Design Vegetation Management
GIS	Environmental	Transmission & Distribution Operations
Grid Operations	Land Management	Transmission & Distribution Design

The SDG&E stakeholders identified for potential participation and solicitation on this project are included below in table 5:

Table 5. Potential Stakeholder Participants

Potential Stakeholder Participants		
Electric Transmission and Distribution Engineering	Vegetation Management	Operating Districts
Electric System Operations	Land Management	Fire and First Responder Coordination
Distributions Planning	Fire Risk Mitigation	Environmental Resources
Transmission Planning	Project Management	Asset and Data Analytics

2.2 Stakeholder Summaries

SDG&E stakeholders were identified by project leadership with the intent to review and document each group's workflow processes and specific requirements for data usage and ingestion. The stakeholders that were identified for participation based on project interest staffing resources were Vegetation Management, Electric Distribution Planning, Environmental Planning, Land Management and the GIS group. Each participating stakeholder was interviewed and/or contacted through questionnaire to identify their data usage and ingestion, required file types and software platforms used during daily processes. Use cases developed from this information were later refined to specific cases tested during the EPIC 2 Project #6. Specific test cases and POCs were designed to meet the requirements for the identified stakeholders. Additionally, use cases and future applications of the data and software were documented to help guide future test cases. Select file formats were identified based on stakeholder needs to ensure the data collection efforts and resulting products met those requirements.

Like the vendors, stakeholders were asked to provide existing and potential use cases for the project. Stakeholders responding to the initial request for participation in the project included Vegetation Management, Electric Distribution Planning, Environmental Planning, Land Management and GIS groups. The results of the inquiry are diagrammed in Appendix B: Vendor-Stakeholder Use Case Matrix.

2.2.1 Vegetation Management

The Vegetation Management team is directly responsible for ensuring that vegetation growth within SDG&E territory is identified and documented for yearly maintenance. It is critical for Vegetation Management to perform routine maintenance for public safety and to be in compliance with regulations set forth by the CPUC. The maintenance prevents vegetation encroachment near power lines. SDG&E has a mission to prevent and reduce power outages for their customers. Power outages are commonly caused by vegetation encroachment as overgrown and diseased vegetation and trees near power lines contact SDG&E structures and energized conductors.

Vegetation Management department currently uses handheld measuring devices to identify vegetation growth, often times in treacherous conditions. From a safety perspective, vegetation encroachment not only causes power outages, but can also spark wildfires. SDG&E employs certified arborists and tree pruning crews year-round to inspect and maintain vegetation clearance standards by ensuring trees and vegetation are cut back to the appropriate distance from distribution power lines. SDG&E currently utilizes a work management application, PowerWorkz, to track the inspection and maintenance schedule of all surrounding trees and their conditions. The implementation of the system has significantly reduced power outages. Leveraging UAS capabilities to gather data regarding vegetation and plant conditions will further enhance work management applications to benefit ratepayers, improve safety, and improve SDG&E's core business.

Use cases for UAS data within Vegetation Management include:

1. **Vegetation Encroachment Identification.** See Test Case in Section 2.5.2 below.

2. **Corrected Locations of Current GIS Assets.** Within SDG&E GIS database there are geographic locations for assets including vegetation. These locations can be erroneous up to a couple hundred feet for certain SDG&E assets. Through data collection using UAS technology these locations could be corrected in the GIS database.

3. **Change Detection on Subsequent Data Sets.** Vegetation Management has a database cataloging species and growth rates vegetation within regulatory limits of SDG&E transmission and distribution assets. Vegetation classification and measurements are observed and recorded by SDG&E field employees on the ground. Vegetation Management is interested in utilizing UAS captured data couple with analysis tools to determine vegetation location, species and separation from SDG&E above ground electrical assets. Additionally, UAS captured data integration into this process would alleviate the necessity of manned field observations to monitor vegetation encroachments and growth rates.

   Currently Vegetation Management does not use nor has access to the imagery and LiDAR data captured through the siloed stakeholder based ASD process. Vegetation management has expressed an interest in having access to collected data along with gaining notification for future UAS capture missions. The group could provide input on collection parameters prior to UAS missions which would allow for vegetation observations and analytics. Additionally, a centralized database for all captured imagery products and LiDAR would allow the vegetation management team to view conditions and plan future projects. Vegetation Management would also like an automated notification process for changes to assets that require monitoring and maintenance by the group.

4. **Sag and Sway Calculations for Encroachments.** Electrical load, ambient temperatures and wind speed create sag and sway in overhead electrical lines and facilities. There are minimum distances between wires, poles, the ground and buildings. These distances are codified in state electrical codes. Sag and sway potential must be calculated as part of considerations for Vegetation Management.

   PLS-CADD currently provides calculations based on existing components to determine sag and sway potential. In a future state, the Vegetation Management group would like to see a platform that can identify encroachments into the sag and sway encroachment area. These areas can vary based on type of line and what equipment is being used.

5. **Identification of Protected Vegetation and Wildlife Species.** The Vegetation Management group is responsible for ensuring that protected species of wildlife and vegetation is not impacted by the operations within their group. Protected vegetation and wildlife species are cataloged in an internal database within the Vegetation Management group.

   Data collected by UAS could positively impact the way Vegetation Management catalogs and assesses potential impact of its operations on these protected species of wildlife and vegetation.

6. **Use Asset Metadata to Predict Growth Rates.** Vegetation Management identified a potential opportunity for leveraging metadata that currently exists within SDG&E databases to predict growth rates of vegetation. The stakeholder group would like to see a future state development of technology to automatically identify potential growth in areas that may come into contact with SDG&E lines.

7. **Use Repetitive Data Sets to Predict Growth Rates.** By collecting repetitive datasets Vegetation Management foresees an opportunity to better predict growth rates of vegetation that has potential to come into contact with SDG&E lines.

2.2.2 Electric System Planning, Engineering and Construction

Executes preliminary planning of electrical distribution lines, prior to engineering. This stakeholder used PLS-CADD format files for distribution pole planning in areas that are often inaccessible to regular ground inspection. Potential uses and impacting transmission and distribution engineering, design, construction standards, materials and project management.

Use Cases Identified for Electric Distribution Planning:

1. **Cataloging and Remote Asset Management.** See Test Case Section 2.5.3 below.

2. **Remote access.** SDG&E has transmission and distribution lines that can be found in treacherous terrain that is difficult for field crews to access. These environments can present many safety concerns that could be mitigated with UAS technology.

   By utilizing UAS technology some of these risks can be alleviated. Field crews will not have to travel by foot as far into unfavorable terrain if the data can be collected by UAS. Pole inspections would require less hiking as a UAS could be launched from a nearby access road and flown to inspect SDG&E assets and collect imagery data on the assets

3. **PLS-CADD integration.** PLS-CADD is a sophisticated three-dimensional engineering model. This model includes the terrain, the structures and all the wires. The model can be viewed in a number of different ways: profile views, plan views, plan & profile sheets, 3-D views, staking lists. PLS-CADD is software used to draft and model SDG&E powerlines. Integration of PLS-CADD was identified from the onset of this project as something each vendor would be required to exhibit within their respective platform.

2.2.3 Environmental Planning

The Environmental Planning group at SDG&E is responsible for the stewardship of the Earth's natural resources and conserving plant and animal species along with their natural habitats. It is their responsibility to protect the wellbeing of SDG&E employees, the public, and the environment and promotes sustainable energy production to meet the needs of the present without impacting the ability of future generations to meet their needs.

The Environmental Planning Group identified the benefit of collecting LiDAR and image data via UAS platform to provide current geospatially accurate electrical equipment and terrain data. The data would be an enhancement to the existing process where the team is using imagery and assets within the Esri GIS environment. Electrical assets within Esri GIS database are based amalgamation of source data derived from records and field measurements. The source data ranges from digitizing facilities from historical paper maps to survey grade geodetic positions. For this reason, and the inclusion of errors due to manual digitizing, projection transformations, some pole and wire locations derived from the GIS database can be off the actual location by a hundred feet or so. The Enterprise GIS Solutions team will correct and re-digitize GIS data, and push the updates to GIS databases, that can be accessed by other departments through GIS applications. With access to current data, the environmental team can complete effective desktop reviews by aligning accurate electrical equipment positions with current photography, cultural resources, water features, vegetation and land ownership. The enhanced desktop reviews will decrease project turnaround time to schedule, approve and execute projects.

Additional benefits would be to limit vehicle and personnel incursions into environmentally sensitive areas.

Use cases identified for Environmental Planning:

1. **Asset cataloging.** See Test Case Section 3.2.3 below

2. **Avian covers.** See Test Case Section 3.2.1 below

3. **Corrected locations of current GIS assets.** The Environmental Planning group for SDG&E would benefit from accurate locations of assets that are mapped and databased within the enterprise GIS environment. When the UAS derived LiDAR and photography data for transmission and distribution circuits is coupled with positional constraints, the assets can be verified via an office review with a high level of confidence. The asset information currently available lacks overall positional confidence to allow for effective environmental planning. If the information available to the Environmental Planning group was accurate, it would create an ability to conduct effective internal desktop reviews of projects. Increasing data accuracy would also increase stakeholder confidence that the pole and associated data locations are accurate in relation to surrounding features. There are several types of features that would be of interest to the Environmental group including vegetation, cultural resources, water features, land ownership, etc.

   Having the ability to quickly access data through the desktop review process would allow the Environmental group to more efficiently review and release projects. Increased data accuracy would reduce the need for site inspections and surveys. These procedures would save time, reduce costs, limit impacts on the environment and improve system reliability.

4. **Access to recent imagery via GIS** – In a similar vein to the use case described above, the Environmental group would benefit greatly from having access to recent imagery in GIS. One potential use for this would be to examine the surroundings of a pole that might need service work performed to minimize impact on the environment in that area.

   Recent imagery provided by GIS would also assist the Environmental group with enhanced ability to provide a desktop review of an area that might have land use conflicts with sensitive locations. Enabling review of hard to access locations like flooded access roads or no access roads.

5. **Annual or Bi-Annual update of assets.** The Environmental Planning group currently relies on existing imagery data as it exists in the GIS database. As UAS practices grow and develop the Environmental Planning group would see an immediate benefit to collecting asset data via UAS on a regular basis, annually or bi-annually. Having recent

imagery can help the group determine what the environmental status of any asset locations that may require a field visit by SDG&E field crews.

6. **Accurate GIS parcel layer.** Parcel layers currently being utilized by the Environmental group can have positional inaccuracies. For projects that deal with sensitive boundary lines, UAS data can be combined with a field survey to provide an accurate parcel lines and existing conditions imagery.

7. **Identifying physical encroachments.** SDG&E GIS has location data on field assets. However, this data can be inaccurate (sometimes up to hundreds of feet). Having the ability to view recent, accurate orthorectified imagery will help the Environmental group identify physical encroachments into environmentally sensitive areas or other SDG&E assets.

8. **Best practices for Data Management.** Data management is an important component necessary for successful implementation of UAS collected data. SDG&E has "silos" of data when it comes these types of datasets. When a group asks for imagery to be collected it is delivered only to the group requesting these services.

   SDG&E would benefit greatly from a unified data management platform. The UAS data collected from the various internal groups and vendors could be ingested into a single platform. The platform could serve as the repository for the UAS data and the source for access to the many stakeholder groups within the company. There would be a standard for data storage and dissemination companywide that would better serve the stakeholders.

9. **Identification of protected vegetation and wildlife species.** SDG&E is committed to protecting the natural resources of California including protected vegetation and wildlife species. Identifying vegetation is currently done manually by field crews on the ground. Identified species are cataloged and put into a database where they can be monitored and viewed via GIS. Wildlife species and nests are identified in a similar manner and stakeholders can view areas that have wildlife concerns.

   In a future state the Environmental group would see a benefit in having a platform that can natively locate and identify wildlife and vegetation through deep learning classification. This would provide a cost benefit by deterring the use of field crews for certain applications. By utilizing machine deep learning a future state platform could potentially locate vegetation and wildlife a field visit might miss. By reducing the amount of field crew utilization this would also prevent exposure to possible safety hazards in environments that can be difficult to access on foot or by vehicle.

10. **Standardization of collection requirements.** Data collection via UAS or fixed wing methods can often produce similar results. Sometimes the data collected is in the correct location for the Environmental group to utilize but the imagery is not captured from a compatible altitude, angle, orientation, etc. Another problem indicated by the Environmental group is that the data being viewed is too old to be used for the group's purposes.

    By establishing standards for the collection of UAS data there would be guidance for how the data is collected, when it is collected and with a standard orientation that would work for the environmental group. Some vendors associated with this project have addressed the issue of too low a pixel count associated with this use case. Having a standard camera setting or distance while capturing data based on the abilities of the UAS and safety factors would be a benefit to SDG&E.

If these use cases were pursued and implemented the Environmental group has indicated the following applications that are pertinent to their group: high resolution aerial photography and 360-degree video of proposed projects (i.e., transmission lines, distribution lines, re-conductor, fiber line, access road, staging yard, etc.). This would be similar to an airborne version of Google Street View for a proposed project. This photography and video could assist Environmental in the following ways:

- Desktop review for land use conflicts and sensitive locations.
- Desktop review of hard-to-access locations such as flooded access roads and overgrown access roads or no access roads.
- Preliminary environmental habitat evaluations. Photography/video of entire pole/facility would capture conditions of the surrounding pole and provide a baseline for desktop review.
- Pre-construction condition of the land and surrounding areas that could be compared to post-construction conditions to avoid disputes from land owners (staging yard land owners, county/city roads, etc.). Updated data could also assist in identifying vacant land for potential laydown/staging yards.
- Emergency Assessment Video/photography after a fire to see conditions of electric transmission/distribution facilities and surrounding vegetation.

2.2.4 Land Management

Land Management handles all land issues related to SDG&E, such as easement encroachment enforcement, conflict detection for development proposals, resolving customer disputes, securing SDG&E project staging yards and land rights interpretation. No test cases were put in place for this group.

Use cases identified for Land Management:

1. **Right-of-way/property encroachments** Land Management is charged with identifying Right-of-Way and property encroachments as related to SDG&E assets. Types of encroachments include: buildings, vehicles, storage of materials, etc. Currently they are relying on outdated and often excessively inaccurate GIS data to view SDG&E assets.

   Accurate and up-to-date UAS imagery that is easily accessible would be a benefit to the Land Management group. The group could view the imagery and compare it with the existing base maps to identify potential right-of-way and property encroachments. This type of data would enable the Land Management group to view recent data remotely from a desktop station. The remote evaluation would reduce mobilization and onsite investigations associated with project planning.

2. **Erosion detection.** Land Management is interested in utilizing UAS collected data to identify potential erosion problems that might impact assets. Currently, erosion issues are primarily brought up by customer complaints and field crews. Utilizing accurate, recent imagery, Land Management will be able to assess areas that might be prone to erosion problems. By contrasting imagery observed over an interval of time, Land Management could detect erosion from the overlaid images.

3. **Locating homeless encampments.** The Land Management Group is interested in deploying UAS technology to identify and map homeless encampments within or adjacent to facilities and easements. Imagery and other multi-spectral sensor technology can detect and identify both people and structures from the remote UAS platform without incursion into the encampments. The technology will provide an increased level of safety for SDG&E and consultant evaluation teams. Newer data could be compared with historic data to compare the changes in the camps over time.

4. **Temporal data storage to identify changes over time.** The Land Management group is interested in the development of a historical UAS image and data repository. Temporal imagery is a useful tool to identify changes over time. Some applications include right of way encroachment management, erosion detection and asset management. Currently there is no infrastructure in place to identify changes in assets, environment or facilities within SDG&E.

   By using UAS data and a central data management platform for temporal data storage Land Management could leverage historic data to report any changes to SDG&E assets over time.

5. **Accurate GIS parcel layer.** SDG&E GIS currently contains raster data obtained through contractors and vendors data. SDGE is currently pursuing the options to add this raster data as reference to advanced analytics and GIS feature location accuracy. Land

Management can view GIS data to give them an idea of where the parcels and facilities are located in a general area, but it is often not accurate enough to utilize for any kind of meaningful decision making.

By incorporating UAS data into Land Management's parcel data it would give the group a clearer picture of what the conditions are like on the ground and how they compare to the parcel lines. This application would also be useful in identifying encroachments.

6. **Corrective Maintenance Program**. Although Land Management is not responsible for managing the Corrective Maintenance Program, they are often heavily involved. A common example is when maintenance needs to be performed on a SDG&E pole, but the landowner has placed fences or structures around the pole preventing access to the pole. LM will get involved, research easements, utilize current and historical aerial photography and resolve the access issue with the landowner.

   By utilizing UAS data, Land would be able to better track what the encroachment looks like and when it may have started happening. Historical information and photographs of facilities are always useful for these types of issues.

2.2.5 GIS Group

The **GIS Group** interacts and support many stakeholders in their business processes. The groups included but are not limited to the Analysis Group, Enterprise GIS Solutions, GIS Business Solutions, Transmission Engineering, Electrical Distribution Operations, Planning, Engineering, Emergency Operations Center, Vegetation Management and Environmental/Cultural. Much of their GIS data is available through the SPARC interface (SDG&E's proprietary GIS portal application relating to Transmission, Distribution, Emergency Operations Center, etc.).

SDG&E's GIS team receives monthly GIS base data updates via contract surveyors and GIS vendors. Additionally, the group has a very active data editing and management effort, performing daily reconciling and posting of edits. On any given week, nearly all circuits have some sort of edit work performed on them. Knowing of updated and current imagery for a given area would assist in both accurate visualization and editing.

The GIS group does not currently request UAS support from the ASD group, though they are aware that the option is available. The GIS team would like to incorporate data generated by UAVs across the board, they have specific interest in the vegetation management use case as well as asset tagging. The group would like to be able to have an automated process to determine images that relate to field assets and tag them or link them to the GIS feature class.
To keep the online GIS portals running at acceptable speeds, the GIS group would like to have a feature layer that could be queried that shows the extent of UAV data without returning the

imagery until it is specifically requested. The feature layer would be updated as needed as field data is collected and made available to the portal(s). Also, the GIS team would like to get the Ortho-rectified imagery added to the GIS applications as base maps, to provide accurate location, and elevation reference to the Editor group for digitizing the assets.

2.3 Use Case Summary

Interviews with stakeholders and assessments of workflows, user platforms, and data management platforms many use cases were identified. Those use cases also helped to identify potential benefits common to multiple stakeholders and their need to catalog and manage assets remotely, such as the ingestion of meta-data tagged RGB imagery or shape files, and the ability to be able to query by asset or geographic location. The used cases identified have impacts to staff and public safety, data lifecycle management, file storage and end user access.
These use cases were reviewed by the EPIC 2 Project #6 Team and test cases described in Section 3.2 below were developed to showcase vendors ability ingest, analyze and report on UAS data and SDG&E assets. See Appendix B: Vendor-Stakeholder Use Case Matrix. for a matrix of use cases identified per stakeholder.

2.4 Project Baseline Data Set

To perform the test cases a data set including the necessary files to complete the tests was developed. This test segment consisted of a SDG&E 1.25-mile segment of a distribution circuit including 30 poles. The test segment was selected due to previous LiDAR data collection as part of the FiRM program. To improve the test segment data supplementation of oblique and grid RGB photos was performed which increased the analysis performed by vendors. The baseline data set of LiDAR flight data, RGB photos, GIS data, PLS-CADD data, design and construction documents along with other various reports and exports was provided to each vendor allowing them to perform analysis, develop tools, and generate necessary reports for the EPIC 2 Project #6 Team. From the given data set vendor were also able to evaluate SDG&E's existing IDMP, collection methods, standards and procedures for design, construction, as-built and maintenance efforts. Vendors that were not able to collect their own RGB imagery due to various project constraints were provided with additional oblique and grid photos for analysis. The project baseline data set included the following:

- 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.
- 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 avian cover analysis totaling approximately 3000 photos.

- Additional RGB oblique and nadir imagery collected at project start was provided to Vendor B, Vendor C and Vendor D only as Vendor A utilized their self-acquired imagery.

2.5 Test Case Summary

UAV, LiDAR and RGB data collection technology has advanced sufficiently so that it may be applied to address specific applications that currently are being implemented through costly field visits and manned aviation assets. By using machine learning and other processing algorithms many of these tasks can be accomplished for less overall expense and on a regularly scheduled basis. By having assets automatically cataloged from high resolution imagery, a more accurate inventory of both assets and asset condition can be maintained. Future applications can then focus on predicting failure based on asset condition as detected by UAS in the normal course of flying SDG&E facilities. In the same manner, vegetation growth and health can be more effectively cataloged, monitored and predictive algorithms can be used to target areas where the growth will soon encroach on the safe zone around the facilities.

A review and assessment of SDG&E's existing UAS operational technologies and practices as applied to their electrical distribution and transmission business was conducted. From the review and assessment, three test cases were developed to collect data via UAVs and apply it to software solutions to satisfy the needs of the use case. All vendors were provided with the SDG&E baseline dataset described in Section 2.4 above. Vendor A chose to utilize their own UAV to collect data for the test cases. Vendor B, Vendor C, and Vendor D were provided with additional oblique and nadir RGB imagery collected by an SDG&E contractor not involved with this EPIC 2 Project #6.

A portion of SDG&E line circuit containing 30 poles was selected for the purposes of testing three use cases.

2.5.1 Avian Cover Identification

Vendors were tasked with ingesting existing RGB data into the vendor proposed platform and demonstrate the platform's capability to identify avian covers, specifically the existence or absence of avian covers where they are required. The long-term goal of this test case is to be able to capture significantly more detailed asset management data and condition assessment with automated machine learning analytics.

This test case was established to evaluate each vendors ability to develop and train machine models that can continuously learn to automatically identify avian covers as new imagery data is introduced to the platform. The model can then be applied to drone captured data to assess whether avian covers are present or need repair/replacement in potential future state.

2.5.2 Vegetation Encroachment Identification

The Vegetation Management Group is responsible for the maintenance and trimming of approximately 4,500 trees and the validation of trimming work performed by contractors on these assets. These services are currently done through physical inspection with hand held measuring devices, often in remote locations and treacherous conditions. This test case was developed to test the ability of vendors to accurately identify vegetation encroaching within a buffer zone around power lines.

2.5.3 Cataloging and Remote Asset Management

SDG&E leadership expressed a desire to use LiDAR and imagery to catalog assets in remote areas and demonstrate change management for those assets. Vendors were also asked to demonstrate extra metadata tagging for relevant data as they relate to assets identified by UAS. This test case was developed to evaluate each vendors ability to ingest SDG&E distribution pole GIS asset metadata into the vendor tool; associate and assign imagery collected via the UAS platform to the GIS asset then demonstrate the ability view, edit and analyze imagery and metadata within the vendors tool.

3.0 Vendor Tools and Test/Use Case Results

The test cases described in Section 2.5 above and baseline data set described in Section 2.4 above were provided to each vendor in order to develop a standardized assessment of each vendor tool. The results for each test case are described in this section.[2]

3.1 Vendor Tool Overview

3.1.1 Vendor A

The Vendor A visualization tool used for this project was Vendor A Tool. This tool demonstrated the ability to ingest and display all files provided in the baseline data set except for the PLS-CADD model file. The demonstration was performed using Chrome web browser.
The tool provides a 2D home page with a map displaying symbols for assets and machine learning analysis results with an option for downloading assets. The tool is also equipped with a 3D reviewer workstation for performing spatial analysis, reviewing asset associated imagery and downloading 3D data sets.

The system allowed control of data sets such as filtered LiDAR point cloud, imagery, video, and annotations in 2D and 3D views. There were also measurement functions such as angle, height, distance, area and volume with different methods for selection. The Vendor A Tool can be installed behind SDG&E's security firewall.

3.1.2 Vendor B

The Vendor B visualization tool used for this project was Vendor B Tool. This tool demonstrated the ability to ingest and display all files provided in the baseline data set including the ability to ingest PLS-CADD model file exports. The demonstration was performed using Google Chrome web browser. Vendor B identified compatibility with Chrome 55 or higher and Firefox 50.1.0 or higher (tested using Windows 8.1 or higher).

The tool provides a 3D home page with color coded symbols representing tree assets ingested from GIS data and avian covers missing or detected. Vegetation encroachments are identified as polygons for the limits of encroachment.
The system allowed specific data sets to be turned on and off through an asset dropdown tree along with discover, search and upload functionality.

[2] Portions of Section 3 were developed and/or quoted directly from vendor presentation or reports given to the EPIC-2 Project #6 team.

3.1.3 Vendor C

The Vendor C visualization tool used for this project was Vendor C Tool. This tool demonstrated the ability to ingest and display all files provided in the baseline data set including the ability to ingest PLS-CADD model file exports. The demonstration was performed using Internet Explorer web browser.

Inside the portal a 3D representation of the network is displayed, from terrain and base imagery through to high resolution LiDAR and asset images. These can all be layered up to provide a rich, detailed view of the as built, as surveyed conductors, structures, vegetation and condition. Vendor C Tool operates using pre-optimized datasets generated following any processing to, allow fast loading, and reduced data volumes to be distributed across the internet whilst maintain the visual quality required for review and condition assessment in the portal. This method was chosen as opposed to the alternative on the fly compression or distributing uncompressed data, as this leads to reduced server load – meaning more users can access the data concurrently, and the amount of data that needs to be handled at any given point, resulting in a smoother user experience.

Vendor C Tool revolves around a central store that then feeds data into the web viewer, this central store can provide feeds into other systems and vice versa. 2D data layers can be fed into other software like Esri ArcMap, ArcGIS Online, QGIS, PLS-CADD as standard Web Feature Service (WFS) / Web Map Service (WMS) feeds that are fully Open Geospatial Consortium (OGC) compliant. Conversely, existing feeds can be fed into Vendor C Tool, allowing data to be integrated into the system, bringing everything into one place, maximizing the amount of information available to inform intelligent business decisions. Once again, this includes standard WFS / WMS feeds and a range of tabular database connections.

3.1.4 Vendor D

The Vendor D visualization tool used for this project was Vendor D Tool. This tool demonstrated the ability to ingest and display all files provided in the baseline data set except for the PLS-CADD model file. The demonstration was performed using Chrome web browser, the Vendor D Tool and CloudCompare software.

The tool provides features including:

- 2D cartometric representation of terrain in the vicinity of power lines using orthophotomap,
- Representation of altitudes of the terrain and objects above ground level by Digital Surface Model (DSM) and Digital Terrain Model (DTM),
- Distance, altitude, area, and volume measurements based on orthophotomap and DTM/DSM (e.g., conducting measurements of distances between the power lines and objects close to them or distances between poles or other devices),

- Ability to attach files like high resolution images and movies showing details of devices installed on the poles (e.g., avian covers), PDF files with documents (e.g., work orders), and notes generated directly in the Vendor D Tool with additional information,
- Establishment of vector data layers for performing analysis by comparison with raster maps layers (e.g., orthophotomap, DTM, DSM) and presentation of the results of GIS analysis performed in external software,
- Generation of vector objects by drawing directly in the Vendor D Tool,
- 3D view for presentation of 3D model of the terrain with or without objects above ground level, based on DTM or DSM with textures made from orthophotomaps and other raster and vector layers with the ability to perform measurements,
- 3D point cloud view for presentation and analysis of 3D point clouds acquired using LiDAR or generated during photogrammetric image processing.

The Vendor D Tool is a cloud based platform which does not require any investments in advance or installation processes due to the fact that it is operated via web browser or mobile app on mobile devices. The platform's dedication to store, analyze, and share image data combined with its personalized functionalities, configuration, and analytics, make the platform a robust solution for supporting daily tasks related to asset management across SDG&E.

3.2 Test/Use Case Results

3.2.1 Avian Cover Identification

This section describes in detail the results for the test case defined in Section 2.5.1 above. The remainder of this section will discuss the approach, accuracy, recommendations for a future state presented by each vendor and a comparison of vendor results and the EPIC 2 Project #6 Team recommendations.

3.2.1.1 Vendor A Results

3.2.1.1.1 Approach

For this test case Vendor A analyzed their RGB nadir and oblique imagery collected during their two UAS flight missions flown by the vendor under supervision by SDG&E personnel. These images provided a much higher resolution than those provided as part of the baseline data set. The images were ingested into a IDMP where work orders were created for annotators to review the images and visually identify avian covers. The vector outlines of the annotations were ingested back to the IDMP and pushed to the Vendor A deep learning tool. In the deep learning tool, a model was trained to identify the objects inside the vector outlines and create a catalog of the objects.

3.2.1.1.2 Results

The Artificial Intelligence (AI) Workbench identified the avian covers with an accuracy of 85% at a confidence level of 80%. As seen in the vendor demonstration, images containing an avian cover were flagged with a positive indicator in the interface so they could then be reviewed in detail by the software user. The user can also then generate a report on number of avian covers detected in the section tested. Avian cover locations were not represented in the Vendor A Tool with a symbol but were identified with a flag on the RGB images that were successfully analyzed. The flags could also potentially be exported to an Esri platform in the future. Additional RGB images were provided for additional training in the machine learning tool with minimal increase in identification accuracy. Avian Cover detection is shown in Figure 1 below.

Figure 1. Example of Avian Cover Detection

3.2.1.1.3 Additional Features Demonstrated

- The machine learning tool showed the ability import and apply additional models trained previously to automatically identify specific features on steel towers such as bolts, as well as material defects such as corrosion on steel frames.

3.2.1.1.4 Vendor Recommendations for Future State

- Provide as-is vs as-design comparisons for assets such as avian guards, pole caps, insulators, transformers and other features
- Detection of other objects, e.g. bird nests
- Advance from image-level to object-level detection by fusing LiDAR & design data with image-level detections to achieve >95% precision with >95% recall
    - o Enables unique object identification and tracking

3.2.1.2 Vendor B Results

3.2.1.2.1 Approach

At the start of the POC, several data sets were provided that were comprised of near NADIR and oblique imagery. After an initial review of the two datasets, deep learning models were developed using the near nadir dataset because it contained the most images (~1500), which was important for building up a large training base.

After manually eliminating any images that did not contain poles from training, an analysis was conducted to determine if avian covers could be detected in an image when the avian cover was ~150 pixels or less. In these cases, while the pole was visible, the resolution was insufficient to recognize the avian cover with the human eye or through deep learning as shown in Figure 2.

Figure 2. Example of Pole Detection with No Avian Cover Detection

To achieve a span of ~150 pixels or greater, it was calculated the horizontal distance from the UAS to pole needed to be 80 feet or less. To remove images that didn't meet this criterion, a pre-processing step was developed that opened each image and calculated the horizontal distance from the UAS to the pole. Images that were taken at a distance greater than 80 feet were removed from consideration.

3.2.1.2.2 Results

With 444 images remaining that met the criteria for training and testing, a final review was made to identify the images that had the closest view of the pole. These 37 images were reserved to use for testing and presenting results.

With a limited training set of 407 images, the initial results of the model produced too many false positives, in many cases identifying objects that resembled avian covers that were not associated with a pole. As a result, an additional processing step was added that evaluated whether the detection of an avian cover was within a small distance of a pole. If the detection of the avian cover was not near a pole, the algorithm would discard the result, which greatly improved the model results.

Using ground truth data, the accuracy of the avian cover deep learning model was validated as follows in Table 6.

Table 6. Accuracy Measurements for the Detection of Avian Covers

	Avian Covers
Actual	36
Detected	32
Missed	4
False positives	8
Precision	80%
Recall	89%

In deep learning methodologies, there are two primary ways of measuring the accuracy of a model: Recall measures the percentage of avian covers that were successfully detected; Precision is a measure of the number of false positives, e.g. 80% precision would mean that a 1/5 of the detections were not of avian covers.

Even with the extremely small training set, the results were excellent - **89% of the avian covers were detected**. With more training data both the recall and precision values would be improved.

3.2.1.2.2.1 Discovering and Reviewing Results

Once the deep learning models were created, they were applied to the reserved data set as a pre-processing step. The images and results were ingested into the Vendor B asset management platform which provides users across the organization the ability to quickly identify poles with missing avian covers.

Search and Discovery of Results

There are two methods to quickly locate assets and the results of the analytics in the asset management platform:

1. "Discover" – Users are presented a map and icon indicating the location of assets as shown in Figure 3 below. Upon clicking on the icon the interface will zoom into the circuit and display the poles on a map. Red indicates no avian covers were detected on the pole. Yellow indicates a single avian cover was located. Green indicates that two or more covers were found.

2. "Search" – The search menu can be used to locate assets by type, e.g., poles, encroachment, or images. Additionally, much like the original data management platform, users can also apply filters to refine results.

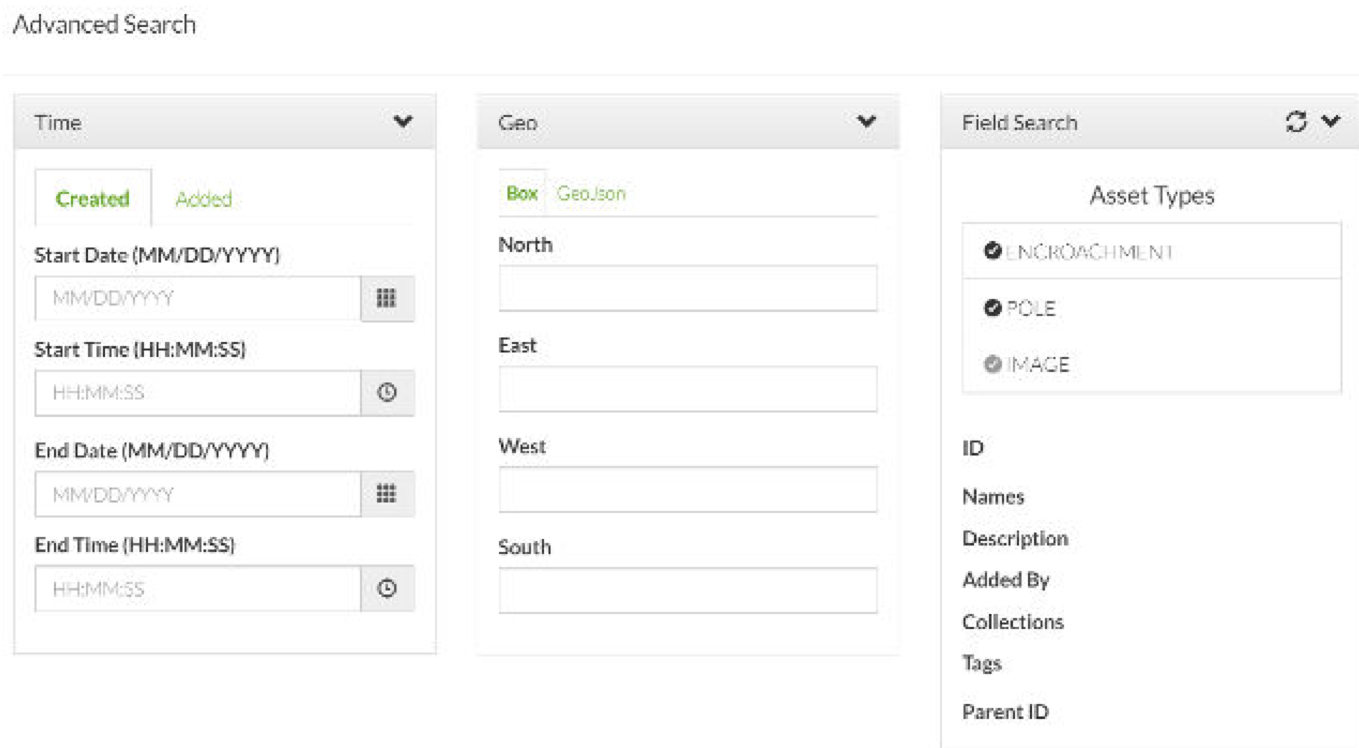


Figure 3. Advanced Search

<u>Viewing Results</u>

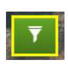
Within the map view, the user can easily navigate around the map with the mouse and zoom in to get a closer look. Users can control what assets (poles, encroachments, or both) are displayed on the map by clicking on the  icon as show in figure 4:

Figure 4. Visual Map of the Avian Cover Detection

While the icon provides a quick indicator of the present or absence of an avian cover, users can view the results by right clicking on any icon. The closest image to the pole that was reserved for testing is displayed in figure 5.

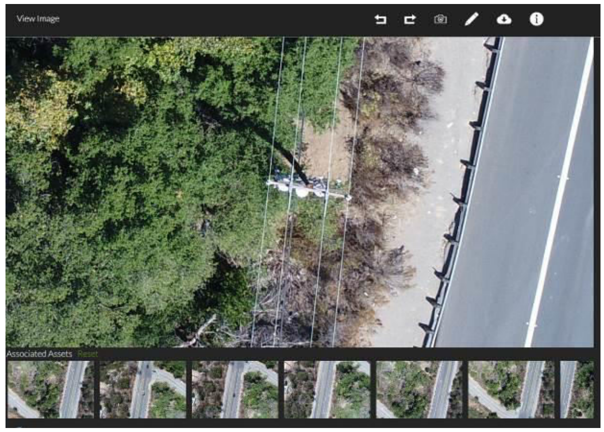


Figure 5. Example of Closest Pole Image

A Pole Report provides key pole information such as the pole identification, GPS coordinates, facility identification, and an inventory list of items detected on the pole such as avian covers and insulators without covers. When the mouse is placed over one of the inventory items in the list, the item is highlighted on the image of the pole as shown in figure 6.

Figure 6. Example of Avian Cover Detected

The thumbnails along the bottom of the screen are other images associated with this pole and can be clicked on to view. These images were used to train the model for deep learning and therefore weren't used to display results.

3.2.1.2.3 Additional Features Demonstrated

None

3.2.1.2.4 Vendor Recommendations for Future State

Vendor B's deep learning technology is a viable and dependable solution for T&D asset management workflows including the detection of anomalies on assets such as the avian cover example. To maximize results in an operational environment, the following recommendations should be considered:

3.2.1.2.4.1 Camera and Sensor Settings

Most image collection platforms offer multiple settings which can affect the quality and accuracy of the analytics run downstream. The following guidelines will help improve results.

1. Capture imagery using the camera's full resolution.
    a. Avoid cropping images or modifying the aspect ratio of the image.
2. Turn the camera orientation metadata settings on.
    a. When using oblique imagery, the camera's orientation metadata (roll/pitch/yaw) is useful in determining if the collected imagery meets collection requirements.
3. When looking for damage types such as a linear fracture (thin line), using the camera's RAW uncompressed format is recommended, which will prevent thin lines from blurring.

3.2.1.2.4.2 Flight/Capture Techniques

The technique used to capture data can greatly affect the probability of success for locating poles and assets as well as identifying anomalies. To maximize results, consider the following when developing a standardized flight plan:

1. Maintain a consistent distance to the pole.
2. Maintain a persistent look angle upon the pole.
    a. Deep learning analytics operate on the original images without considering the look angle or where the image fits in the larger mosaic. For this reason, it helps to have a consistent view of the pole in all the images so that the algorithm can more effectively "learn".
    b. The camera used during the proof of concept had excellent resolution. At that resolution, the UAVs could fly 30-50 feet away from the pole and identify objects or damages with a size greater than 4mm. This distance should be sufficient to detect most damage types.
    c. Before embarking on a major collection, it is recommended that test flights be performed at varying altitudes to determine if the desired object or damage can be identified at that height.
3. Utilize a data validation tool when collecting data.

a. A data validation tool will help reduce costs and ensure the data collected in the field meets downstream analytic requirements. Data validation tools provide pilots feedback in the field to ensure:
    i. The resolution required for analysis is met.
    ii. Proper focus is maintained throughout the capture.
    iii. All required metadata is present and within specified criterial for the capture.
    iv. Proper overlap and coverage for stitching and analysis purposes.

4. Provide the orientation metadata such as roll/pitch/yaw with the imagery.
    a. The orientation metadata is useful when capturing oblique imagery. The camera orientation can quickly determine if the data meets the analysis requirements.
5. Wait for GPS uncertainty to be reduced before starting image capture
    a. FLT log files from the GPS can take a minute to obtain low error bounds. To ensure accurate GPS coordinates, it is recommended that a few minutes be given between when the GPS is turned on and data capture begins.
6. Avoid capturing imagery in poor weather conditions (low light or wet objects change color and can reduce detection results).
7. Avoid capturing imagery in poor lighting conditions (excessive shadows or low sun angles can reduce the pixel range over objects thus affecting detection results).

3.2.1.3 Vendor C Results

3.2.1.3.1 Approach

3.2.1.3.1.1 Manual Identification

Vendor C did not perform automated asset identification using machine learning. For this test case, a range of manual assessment methods were tested and evaluated. This was focused on understanding the consistency and limitations in the asset photos and using human assessment to identify presence on a selection of lines. This was expected to be highly accurate and thus serve as both a verification and training set for later method testing. It would also be used to demonstrate the display of avian cover locations in the online system. See figure 7 below:

Figure 7. Image Containing an Avian Cover

A review of the available images saw significant variability in the quality that was available, which made identification difficult in some instances but always possible. Initial indications were that the imagery was not going to be suitable for automated analysis without significant work or error rates. Figure 8 and 9 below shows the imagery of the Avian covers.

Figure 8. A selection of Avian Covers From the UAV imagery

Figure 9. A selection of Avian Covers from the UAV imagery Continued

3.2.1.3.1.2 Automated Identification

Having reviewed the supplied data and considered the manual methods available for identifying the avian covers, the next stage is to explore a way of automatically detecting their presence. The most appropriate methodology in this case, given the variability of the data inputs, is a machine learning approach. The principle is to create a machine learning system that will accurately identify the presence of the covers and collate this information in a way that it can be used. A prerequisite of this approach is the automated matching of photography to the asset and a degree of consistency in the way in which photographs are taken – considering resolution, perspective and color balance.

The online 3D system used to show the results is not optimized for data analysis – it acts as a portal to link and explore the data and the results, not the analysis itself. As a result, were further time available in this trial, the chosen method would have been the detailed use of the internal machine learning group. Following engagement with the relevant technical specialists from this group, it appears to have the right mechanisms to rapidly train a machine-learning derived system (using object-based recognition) which can be used to identify a desired set of survey objects fast and effectively. In order to achieve this, we must prepare the system through the provision of an extensive library of target images - these images must include visual representations of the target object in a multitude of different conditions as depicted in figure 10.

Figure 10. Image Segmentation Via Machine Learning Platform

In the case of SDG&E's avian covers, the first hurdle would be to manually filter the full set of existing poles present in the supplied imagery which included avian covers and then to apply a range of image manipulation techniques to generate an appropriate training set. These could include the use of cropping and contrast adjustment to highlight the appropriate section of the tower – the avian cover.

3.2.1.3.2 Results

Vendor C did not perform automated asset identification using machine learning. For the trial, based on some simple business rules, technicians reviewed the set of images that had been georeferenced and stored in the online system. The presence of a cover was noted along with the number of phases that included.

Table 7 shows the sample area:

Table 7. Pole Count

Pole Count	
Number of poles	28
Photographed poles	21
Uncovered	11
1 Cover	1
2 Covers	7
3 Covers	2
Unknown	7

3.2.1.3.2.1 Display in the online system

The asset images themselves were displayed for the trial by using two elements:

1. Figure 11 is displaying based on the image capture location and using a 'hovering thumbnail' to enable the user to intuitively relate the photo to the nearest asset.

Figure 11. The Display of Avian Covers Alongside Contextual LIDAR & Image data

2. Creating a colored coded symbol for each image (that related to a single pole) which represented the cover status – that is 0-3 phases covered (white being no cover and dark blue being all three phases) as shown in figure 12 below.

Figure 12. The Display of Avian Cover Symbols To Enable Rapid Review Of The Line Status

Where a photo was not present for a pole, no status was created. This approach enabled a fairly rapid and intuitive assessment of a given line as to the cover status. With further effort on the automated matching of photos to the assets, this display mode could be made more intuitive in use – for example by symbolizing the poles themselves, including those which have no photo (meaning no cover status).

3.2.1.3.2.2 Considerations for further testing

Due to the scope of the provided dataset and the scale of each image provided we believe that the existing Machine-Learning System will be unable to efficiently identify the target objects due to a sheer volume of noise/false positives in the supplied raw dataset, by applying the image manipulation techniques and provisioning further training data, we believe that we will be able to produce a meaningful test output.

This step can be achieved by further utilizing the metadata that is included with imagery and in future imagery, seeking improved metadata (in terms of accuracy and precision). This includes information such as the direction of the photograph, the angle in which the imagery was taken and the pole heights. This will allow us to mathematically identify the top of pole in the image and so target the object recognition more effectively. This method is only realistically viable when using a stabilized and orientation recording mount, due to the unreliability in terms of stability when the data is collected via a human operator.

In terms of the calculations needed to determine the area in the image, see figure 13 diagram detailing the information need and how it is utilized.

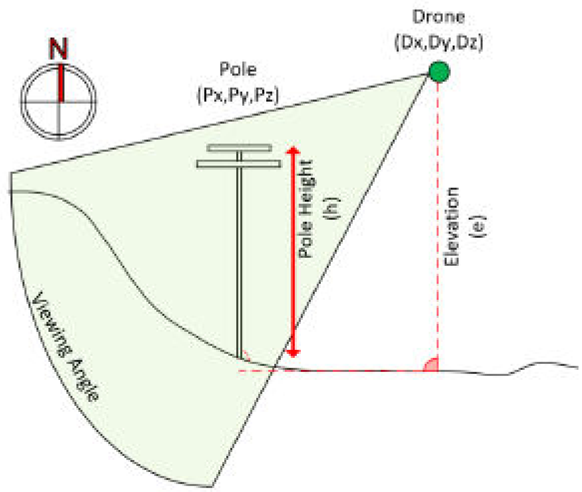


Figure 13. Target Parameters

A secondary method of identifying these covers would be to utilize the LAS data that was collected during the capture phase of the project, using this data we can generate buffers to limit down the target area to help aid the identification process.

Once this data is filtered we will be able to generate a las based image of the pole from a certain angle, and once again utilize the machine learning system to identify the cover. This method would require more effort in the training stage, however this would minimize imaging issues such as weather conditions, image resolution, image quality. But by working with LAS will allow the detection of the top of the pole to be done at higher speed and with more accuracy.

3.2.1.3.2.3 Stage 3 – automated condition assessment

The premise on this item was to make use of the same machine learning platform and explore in a limited way the ability to find defects on the covers. However, the limited training dataset available and the time for this project meant that progressing to this stage was not feasible. However, there are some automated methods that should be relatively feasible as a follow-on initiative:

- Automatically validating installation records on poles via the asset photography to validate the presence of covers and alert to discrepancies (cover in place but not recorded and cover not in place but recorded)
- Categorizing cover types where different methods are used, based on color or construction methods
- Identifying gross damage to covers (for example, if two phases are covered but one is not)

In the short time available, it was possible to explore the way in which the avian cover data could be intuitively displayed to enable an asset manager's assessment, make some initial observations on the data extent and quality and collect some initial statistics for the presence and nature of the covers on the line of interest. It is clear that to reliably use machine learning techniques to carry out a simple presence identification, then the imagery would need to be more consistent in terms of angle and resolution. The use of LiDAR-derived geometries and capture angle/position information for the photos would help to target the machine learning approach by focusing on certain aspects of the image to reduce noise. Further work could test these ideas and also identify the minimum resolution needed to identify the different types of damage that occur. It could also explore the use of 'geopointing' UAV cameras based on LiDAR/model derived targets to enable pole top photography from the UAV platform that was of very high resolution and quality.

3.2.1.4 Vendor D Results

3.2.1.4.1 Approach

For this test case Vendor D analyzed the RGB nadir and oblique imagery collected during the two UAS flight missions that were flown as part of the project. Acquired data was used for deep learning models training. The analysis team utilized images taken during drones' free flights, oblique imagery of poles, and image data gathered in single and double grid autonomous flights. Additionally, the team gathered images of avian covers from handheld cameras for training.
All image data were labeled with an open-source graphical image annotation tool called **LabelImg**. Labels were stored in .xml files, and were applied to objects representing the following classes:

- Pylon head with avian cover - Heads of energy (distribution) poles with minimum one avian cover on the energy lines shown in figure 14 below

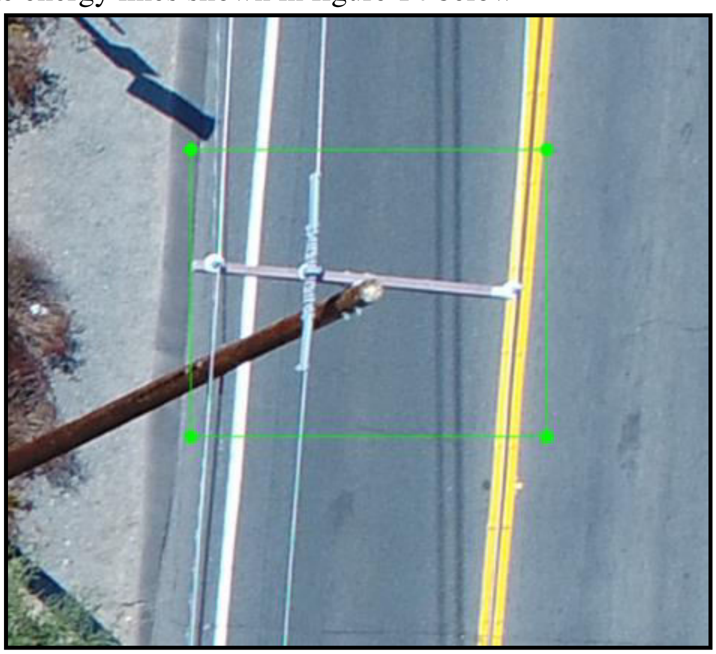


Figure 14. Example of Pylon Head With Avian Cover Label

- Pylon head without avian - Heads of energy (distribution) poles without any avian covers as shown in figure 15 below

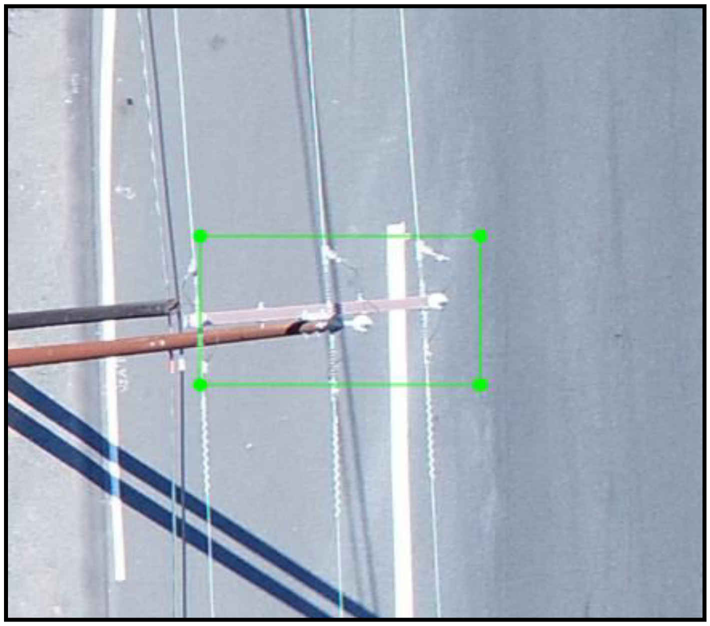


Figure 15. Example of Pylon head Without Avian Cover Label

3.2.1.4.2 Results

After 800,000 steps of training, all of the models gave results of almost 100% accuracy. The model was tested on the additional test dataset provided (one that has not been involved in any phase of training) and proved its high accuracy as shown in figure 16

Figure 16. Bounding Boxes Based on Trained Model

Accuracy checks were made both analytically and visually and detailed results of precision are shown below:

Table 8. Results of precision

Model	Overall Precision	Pylon head with avian Precision	Pylon head without avian Precision	Avian cover Precision
All data	0.9908	0.9961	0.9993	0.9769
Handheld	0.9948	0.9992	0.9999	0.9856
Free flight	0.9973	0.9995	0.9999	0.9924
Single grid	0.9990	0.9999	0.9999	0.9971
Double grid	0.9958	0.9978	0.9999	0.9898

3.2.1.4.3 Additional Features Demonstrated

- Detected 2 assets essentially, avian cover and distribution poles.

3.2.1.4.4 Vendor Recommendations for Future State

The chosen methodology to evaluate avian cover inventory added accuracy and efficiency, and demonstrated a potential for cost reduction when auditing grid elements. The machine learning techniques used for computer vision were an effective way for detecting and inventorying not only avian covers, but a host of additional grid elements. SDG&E should consider the following recommendations for additional machine learning benefits:

- Expand upon systems developed during use case.
    - Systems may be expanded to utilize additional features which can contribute to automation of detection processes, therefore increasing its effectiveness and decreasing SDG&E's costs regarding fines for absence of avian covers on the power lines.
- Review all field work processes.
    - SDG&E should review all of its processes concerning field work connected with power lines inventory, maintenance, monitoring, and vegetation management to assess which processes can be improved with deep learning and computer vision algorithms carried out on a low altitude aerial image data.
    - It would also be beneficial for SDG&E to check how trained models perform on image data acquired with the use of different platform.

***Note:** Several tasks concerning the developed deep learning system extension must be completed before the system is complete and usable:

1. Testing of cropping images with different dimension and stride:
    - Changing the parameters of the imagery used for model training may affect the training time and accuracy.

- Lower width, height and stride of cropped images can extend dataset elements number, which may improve computing time and algorithm efficiency.

2. Extracting localization information from images:
   - All images taken with a drone are geotagged, which means that coordinates of the drone were measured at the moment of taking a photo.
   - Depending on the hardware, GPS receiver accuracy may differ.
   - More advanced drones have GPS Radio to Kinetic (RTK) or Post Processed Kinematic (PPK) receivers (horizontal and vertical accuracy < 5 cm), which are also equipped with the IMU system for measuring camera angles at the moment of photo acquisition.
   - Localization information may be extracted for each image and can be used to identify the pole on which detected objects are present. It may be used for reporting or preparing GIS or CAD files containing geospatial and descriptive information about the examined grid.

3.2.1.5 Comparison of vendor results

The test section was examined visually by the project team via desktop using images taken by private contractor in conjunction with the pole and structure data provided by the GIS group. This manual examination determined that there were 15 poles in the test section that had one or more avian covers. The total number of covers spread out over these 15 poles totaled 32. The table below shows the results of the vendors ability to identify the avian covers.

Table 9. Ability of vendors to identify the avian covers

Vendor	Recall	Precision	Confidence	Minimum Pixels Required
Vendor A	85%	70%	80%	300
Vendor B	89%	80%	95%??	150
Vendor C[3]				
Vendor D	>99%	>99%	>99%	<100

3.2.2 Vegetation Encroachment Identification

This section describes in detail the results for the test case defined in Section 2.5.2 above. The remainder of this section will discuss the approach, results, recommendations for a future state presented by each vendor and a comparison of vendor results.

3.2.2.1 Vendor A Results

3.2.2.1.1 Approach

For this test case Vendor A analyzed the LiDAR data set collected during their UAS flight missions. The LAS point classifications were mapped to PLS-CADD point codes per the SDG&E TE-0135 LiDAR & Imagery Standard. A rectangular 3D encroachment zone utilizing adjustable height and width parameters relative to top of structure, bottom of structure and conductor point of attachment was used for this POC as shown below.

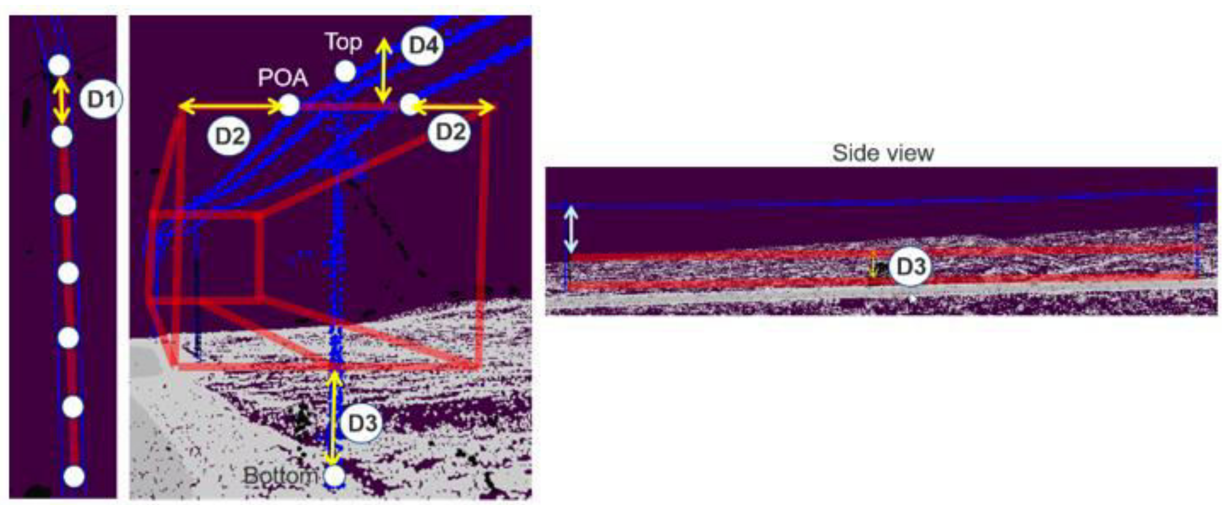


Figure 17. Vegetation Encroachment Zone Definitions

The analysis for vegetation encroachment was performed using vertical cross sections perpendicular to the span alignment and sampling three meters worth of data at a time. Advanced analytics were then performed to identify vegetation within the said 3D encroachment zone for each three-meter segment. Three sets of height and width parameters were visualized for the user by red, yellow and green markers.

3.2.2.1.2 Results

The vegetation encroachment analytic tool could identify encroachments in multiple three meter segments between pole assets with respect to existing vegetation classification of the input LiDAR data. Vendor A also expressed the ability to change the shape of the encroachment zone and incorporate sag and sway parameters in the future. The PLS-CADD model and DXF exports were not used as part of the advanced analytics or demonstration.

3.2.2.1.3 Additional Features Demonstrated

- Ability to link three closest tree assets to vegetation encroachment notifications to show potential increase in efficiencies identifying corrected asset locations.

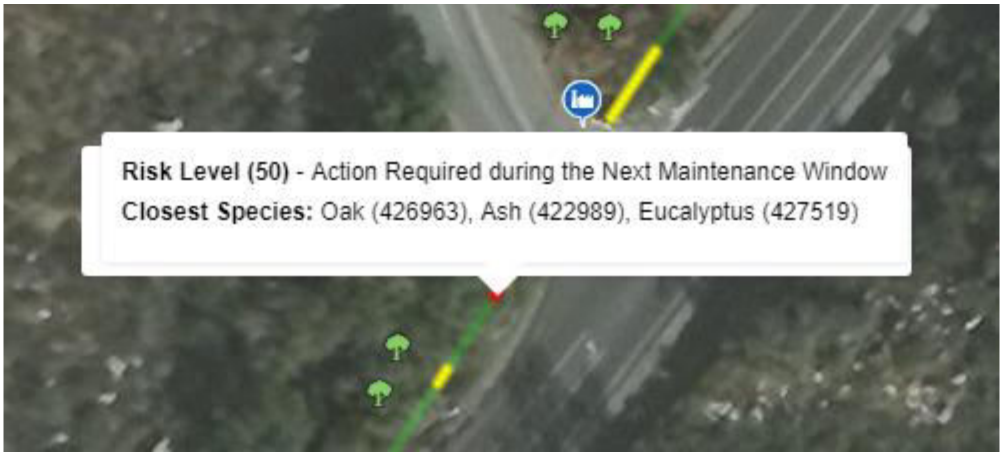


Figure 18. Link 3 Closest Vegetation Assets

- Demonstrated ability to select a point in the LiDAR cloud and query images showing the location using geotagging and orientation of photos.
- Vendor expressed the ability to use tubular encroachment zones along the wires with multiple zones of analysis.

3.2.2.1.4 Vendor Recommendations for Future State:

- Full integration with PowerWorkz and nightly syncs to track asset characteristics: species, growth rate, up to date height.
  - Click & comment to update/track historical data & status for the asset.
- Point and Click image display functionality to include vegetation assets.
- Work order based image ingestion for trimming documentation & verification.
- Customized encroachment zones based on regulatory and SDG&E practices to integrate with worst-case sag and sway analysis.
- 3D encroaching vegetation volume assessment and RGB image verification for costing analysis.
- Rule-based risk score computation based on volume, species growth rates, conductor type and sag/sway analysis.

3.2.2.2 Vendor B Results

3.2.2.2.1 Approach

For this test case Vendor B used two datasets provided that included a classified LiDAR point cloud (in LAS or LAZ format) and a PLS-CADD model of the conductor lines that were exported as a DXF file. The datasets single LAS file contained approximately 20 million points. The points were classified into a number of feature classes.

An ‘as-built’ PLS-CADD model, which was derived from the same LiDAR point cloud, provided geometric alignment between the two sources. With the focus on conductor lines, the DXF file was ingested and the conductor lines were separated into their own shapefiles. The remaining structures, such as telecom lines and pole structures were defined as outside of scope for this test case.

Next, the point clouds were ingested to build spatial indices that would allow for fast geometric queries. Algorithms were developed to evaluate the 3D positions of every conductor line in the PLS-CADD model and identify the LiDAR points that were both classified as vegetation and were within a specified distance to the conductor line. The vegetation points that were identified as potential encroachments were clustered into groups and a bounding polygon was created around them as shown below.

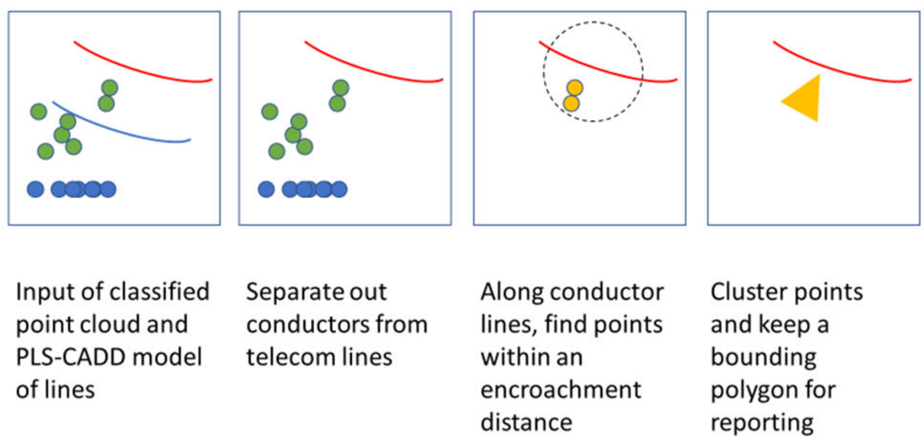


Figure 19. Encroachment Workflow Diagram

The polygons and supporting metadata, including the closest encroachment distances for the cluster, were then ingested into Vendor B’s asset management platform.

3.2.2.2.2 Results

The algorithms to identify encroachments were calculated during a pre-processing step. The images and results were ingested into the asset management platform, which provides several interfaces to quickly identify vegetation encroachments for conductor lines.

3.2.2.2.2.1 Search and Discovery of Results

There are two methods to quickly locate assets and view the analytic results in the asset management platform:

1. “Discover” – Users are presented a map and icon indicating the location of assets. Upon clicking on the icon, the interface will zoom into the circuit and display the poles and encroachments on a map. Encroachments are identified with a tree pushpin that is color coded based on how close the vegetation is to the conductor. Red indicates vegetation

was detected within 10 feet. Yellow  indicates within 10- 12 feet, and green  indicates within 12 - 15 feet.

2. “Search” -- The Search menu can be used locate assets by type, e.g., encroachment, poles, or both. Additionally, much like the original data management platform, users can also apply filters to refine results.

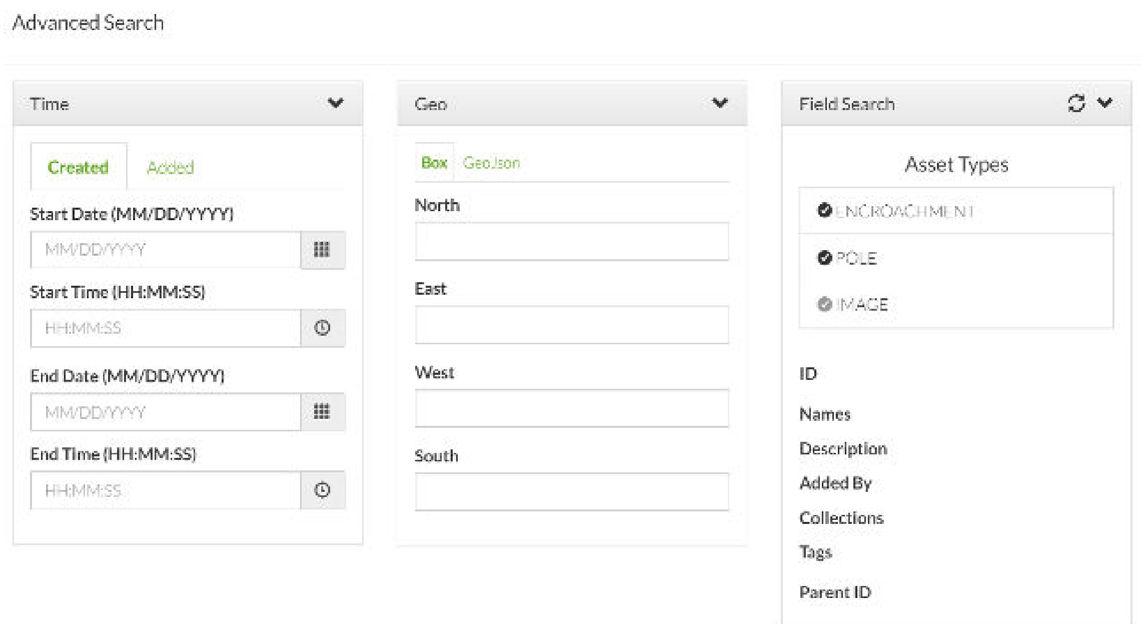


Figure. 20 Advanced Search

3.2.2.2.2.2 Viewing Results

Using the mouse, users can easily navigate and zoom into assets on the map. Using the  icon, users can control what assets (poles, encroachments, or both) are displayed on the map. Along with the location of the encroachments, a 2D polygon is also shown that highlights the footprint of the encroachment area as shown in figure 21.

Figure 21. Visual Map of Detected Vegetation Encroachments

Users can view the encroachment results by right-clicking the vegetation encroachment pushpin. A 3D point cloud viewer is opened with the camera pointed at the selected encroachment. By pressing the “x” key, users are taken on an automated orbital flight of the encroachment. During the flight, users can pause and resume the flight by pressing the “x” key. Users can also manually view the results using the mouse to navigate the point cloud (hold down shift to slow the speed at which the camera moves) as shown below.

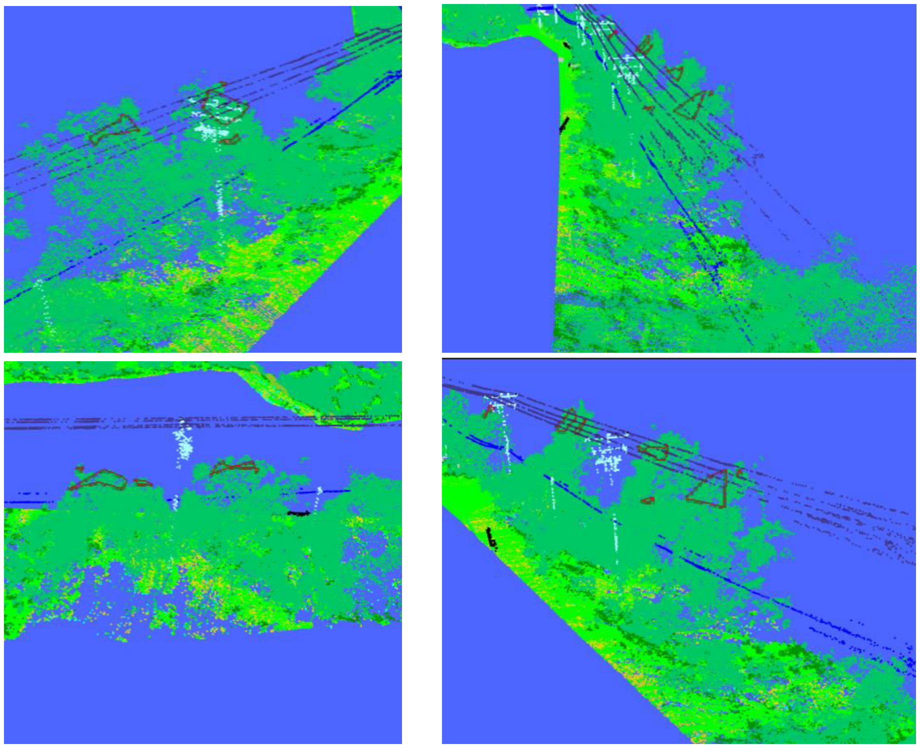


Figure 22. Sample LiDAR Views of Encroachments

3.2.2.2.2.3 Findings

Using LiDAR point cloud data and PLS-CADD models, algorithms were successfully developed to locate and categorize vegetation encroachments that were of potential risks to conductor lines. During this effort, the following observations were made:

- Encroachment detection can be accomplished reliably. Furthermore, given the computational efficiency, processing of large areas can be scaled up using distributed computations.
- The resulting encroachment areas can be made searchable and accessible across a large geographic area.
- The LiDAR collection, point classification, and derived PLS-CADD models resulted in inputs of high enough resolution to support vegetation encroachment detection. The LiDAR was of good quality and density.
- Encroachments can be associated to individual spans and physical assets.
- While not within scope of this test case, stakeholders indicated there was a desire to enable tracing of encroachments back to specific and known trees. Unfortunately, it was determined that the locations of known trees in the GIS were not sufficiently aligned with the LiDAR data to support tracing encroachments back to specific trees. Further data collection and analysis could lead to a solution to address this need.
- LiDAR and PLS-CADD based solutions offer opportunities for automated solutions to detect vegetation encroachments as well as potential clearance violations.

The test case was successful in identifying a number of regions with potential vegetation encroachments. One small area of vegetation was found within 10 feet of the conductor lines, and several other areas were identified where vegetation was within 12- 15 feet of conductor lines.

3.2.2.2.3 Vendor Recommendations for Future State

This test case was successful and proved the technical risk to a LiDAR-based vegetation encroachment solution is small. It is recommended further study be conducted to determine how this technical capability can be deployed into an existing vegetation management workflow. Recommendations include:

- Identifying workflows for updating existing GIS data with accurate LiDAR geolocation information that will support tracing encroachments back to a known existing tree or identifying a new tree.
- Exploring techniques for automating the process of performing point cloud classification and PLS-CADD model generation. Potentially performing the vegetation encroachment without PLS-CADD models.
- Identifying workflows for customizing encroachment parameters and PLS-CADD models to be used for vegetation encroachment.
- Investigating how to quantify the volume of vegetation in an encroachment and mapping the volume, heights, and tree species into a cost model to estimate remediation costs.
- Distinguishing between encroachments likely to 'fall in' to the path of the conductors from those that grow up and into conductors.
- Fusing drone or other aerial imagery with the LiDAR point clouds to enhance the visualization of encroachments.
- Developing interfaces between the demonstrated vegetation encroachment analytics and existing work order management systems.
- Identifying trends by comparing results from year to year.
- Exploring predictive analytics to anticipate areas most likely to have rapid vegetation growth.

3.2.2.3 Vendor C Results

3.2.2.3.1 Approach

For this test case, Vendor C ingested PLS-CADD outputs described in Section 3.2.3.3.1.1 below for comparative analysis. The outputs included models of wires including sag/sway at max load and 80MPH winds. Encroachment buffer zones were projected along the wires to identify encroachments in each zone with a different color.

3.2.2.3.2 Results

The datasets provided had been subject to a simple radial clearance vegetation analysis process based on the PLS-CADD modelling. The purpose of this is to identify against policy or regulatory requirements, vegetation that infringes the minimum clearance distance or is within a cut-back requirement as seen below.

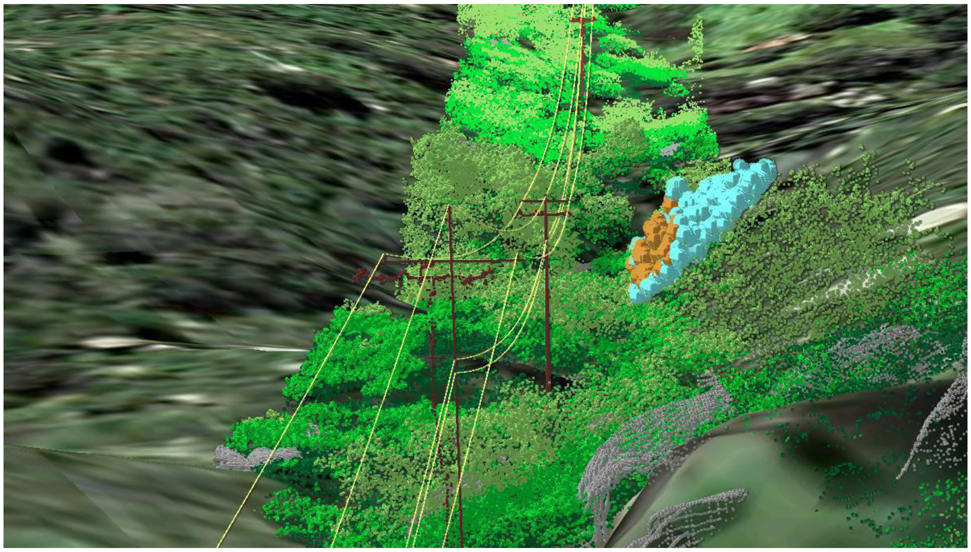


Figure 23. Classified Vegetation Encroachments.

3.2.2.3.3 Additional Features Demonstrated

- Vendor C Tool demonstrated the ability to identify encroachments using customized outputs from PLS-CADD.
- Multiple outputs of PLS-CADD could be ingested during the standard workflow to represent different load and weather conditions.
- LAS files ingested contain PLS-CADD feature coding per SDG&E standards
- Vendor C expressed the ability to automate work orders with specific requirements and integrate attributes collected in the field such as updated geographic locations.

3.2.2.3.4 Vendor Recommendations for Future State

3.2.2.3.4.1 Data Integration and Management

The Vendor C Tool environment provides the opportunity to integrate many different data sources from internal departments with external datasets:

- Integrating vegetation management intelligence with asset condition or engineering information through a platform widely available to personnel throughout a company can facilitate communication and cooperation. With this in mind Vendor C Tool could help identify situations where resources for inspection activities (by different departments) could be shared, potentially helping to cut costs associated for multiple departments.

- We can also split the LiDAR vegetation canopy into more manageable units of single or small groups of trees. Work could be completed to transform these canopy objects into 3D object within Vendor C Tool. This would allow the synergy of existing valuable vegetation records, such as tree species or date of last cut, recorded in the field, to be integrated and made accessible through these objects. These records could then be augmented and updated as required, to ensure the information stored in the Vendor C Tool system remains current.

- Integration of spectrally rich airborne or satellite based imagery into Vendor C Tool could be used to provide the capability to aid identification of stressed vegetation, at a greater risk of fall or catching fire.

- The integration of external datasets, such as spatial representations of high fire-risk areas, or the location of high traffic transport routes or high value assets could also be attributed and visualized. These could be used to gain a deeper understanding of the consequence should a vegetation hazard occur, allowing managers to make more risk based management decisions.

- There is capability to develop interactive interrogation of the databases behind Vendor C Tool, allowing for fully configurable queries. This could provide flexibility to be utilized business-wide, tailoring queries to different management goals in the different aspects of the business, ensuring full utilization of the data.

Holding multiple datasets in one platform with spatial relations and joins, ensures datasets are current, removes issues of data duplication and makes viewing and generating vegetation related reports more efficient, saving costs in time and duplicated data entry effort.

3.2.2.4 Vendor D Results

3.2.2.4.1 Approach

The purpose of developing the proof of concept on vegetation management with UAS was to identify potential applications of LiDAR point cloud, aerial images, and derivative photogrammetry products to form an approach for most effectively utilizing each type of data. By creating a synergistic approach to using different types of data, data will be thoroughly utilized and reusable, resulting in cost savings for SDG&E.

The major considerations during use case development were:

- Most effective algorithm for locating vegetation to be cut down.
- Possibility of performing fully autonomous detection of powerlines and trees on LiDAR point clouds and drone images, and quality of detection.
- Data type that is best suited for the use case (LiDAR vs. aerial image, or combination)
- Combination of data types to obtain best results from the technical and economical point of view.

The data used to develop the Vegetation Management proof of concept are as follows:

- Classified LiDAR point cloud acquired from drone on September 24, 2016, provided by SDG&E and products based on LiDAR:
  - Digital Surface Model
  - Digital Terrain Model
  - Canopy Height Model
- Photogrammetric products based on a dataset of 3133 images in natural colors acquired during photogrammetric drone flight mission on September 19, 2017 as a part of EPIC initiative:
  - Dense point cloud
  - Orthophotomap
  - Digital Surface Model
  - Digital Terrain Model
- GIS and CAD data provided by SDG&E
  - Geospatial database containing geometric and descriptive information on high vegetation (trees) occurring on the analyzed area.
  - 3D CAD data presenting analyzed powerline.

The rationale for using both aerial images and LiDAR data is that the two types of data express different characteristics.

- Aerial images:
  - Contain visual information for generating high quality/high resolution orthophotomaps.
  - Generate colored dense point clouds.
  - Algorithms used to generate products are not suited for representing thin objects like wires.
- LiDAR data:
  - Contain information on the intensity of laser beam reflections (no information on colors).
  - Has a lower horizontal resolution.
  - Represents thin objects like wires and poles clearly on LiDAR point cloud.
  - LiDAR technology penetrates vegetation and contains information on the terrain and other objects covered by plants that are hidden from aerial images.
  - More easily recognizes types of objects (terrain, buildings, vegetation, etc.).

It is important to note that LiDAR sensors for UAS are relatively new and the technology is expensive. LiDAR solutions run at a higher cost than solutions using photogrammetric sensors.

3.2.2.4.2 Results

The analysis broke down into the following steps:

- Tree detection.

- Calculation of the distance between detected trees and wires.
- Direct calculation of the distances in the point cloud.
- Identification of the trees which are either too close to the wire or higher than the distance to the wire.
- Recording of the trees to be taken out due to creation of potential firebreaks.

Tree detection

The first step of point cloud processing was automatic detection of trees. The accuracy of the results mainly depends on the type of the landscape and the quality of the data acquired. Two different algorithms were deployed in order to define the best approach in this particular case. Algorithm A is a modification of the approach proposed by Eysn et al. (2012) developed in ArcMap while algorithm B is implemented in Global Mapper.

The workflow in Algorithm A consisted of the following steps:

- Digital Terrain Model calculation from Ground LiDAR class.
- Digital Surface Model calculation from High vegetation class.
- Canopy Height Model calculation from DTM and DSM.
- Local maximum height calculation.
- Detection of tree tips.
- Selection of trees higher than the defined threshold.
- Conversion of raster to shapefile.

A leading practice for successfully detecting trees is to adjust the parameters that describe the spread and height of trees. Since these values vary for different landscapes and locations, it is crucial to perform tests on real data. In algorithm A, two parameters were altered:

- Search radius for calculation of local maximum height (can be identified as the maximum spread of the tree).
- Minimum height of the tree.

Six sets of parameters were tested on LiDAR point cloud for the purpose of this report. The results were then assessed visually in comparison to the point cloud and orthophotomap for a chosen test area. Comparison to the orthophoto was also performed because it is challenging to identify singular trees in LiDAR cloud manually. There are noticeable difference because the

LiDAR point cloud and images were not simultaneously acquired and are not perfectly aligned. The best results in terms of properly detected trees were achieved in the 5th set of parameters as shown in figure 24 below.

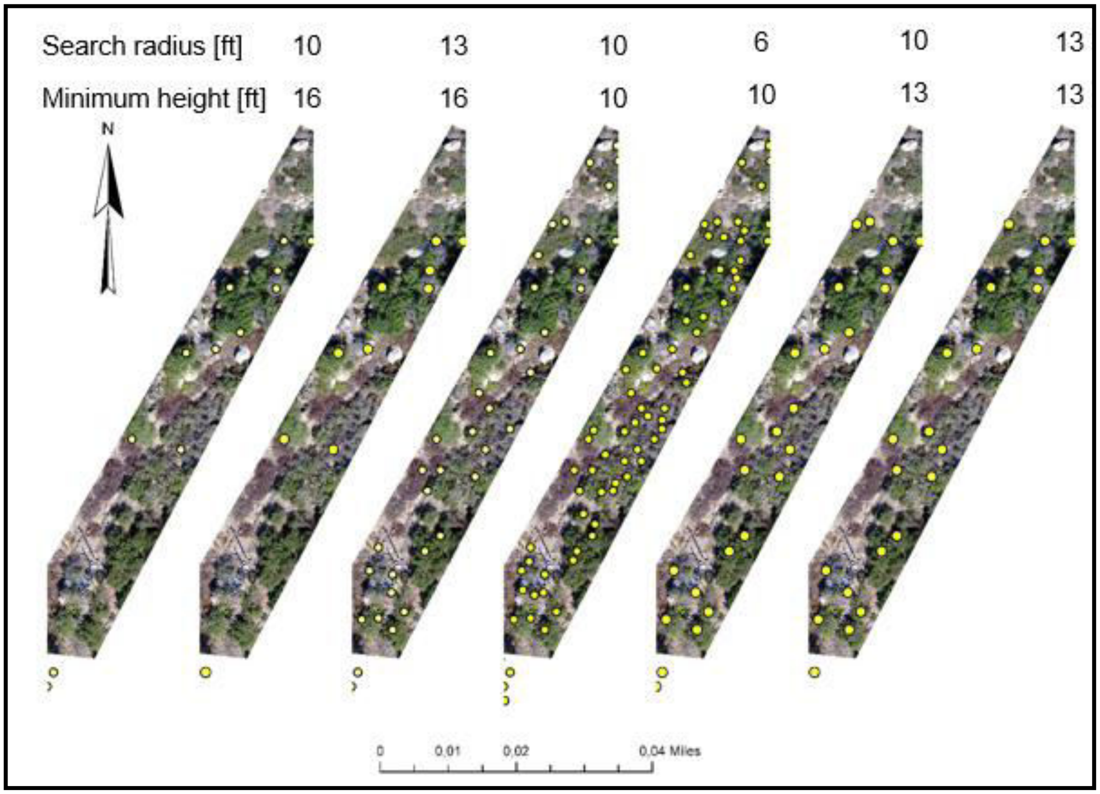


Figure 24. Comparison of Tree Detection Results from Algorithm A

When testing algorithm B, LiDAR point cloud was also used to detect trees. However, Algorithm B missed a significant amount of trees in big clusters, which was not an issue in the case of algorithm A. It is important to stress that within clusters, it is extremely challenging to find single trees manually. While comparing results of both algorithms, it was noticeable that algorithm A was more successful in tree detection. More trees were accurately detected especially in the case of big clusters of trees as seen in figure 25.

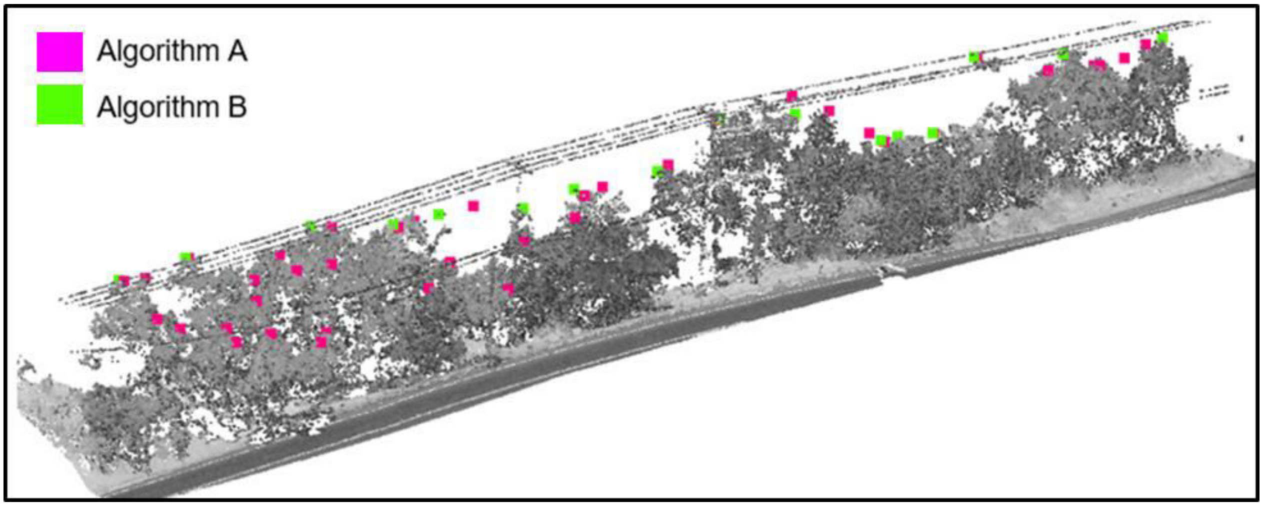


Figure 25. Comparison of Algorithm A and B Results

The analysis team then compared algorithm A to the SDG&E vegetation dataset. Since the SDG&E vegetation data mostly contained trees higher than 20 feet, the same threshold was applied on the algorithm A's dataset. Results of the comparison are shown below:

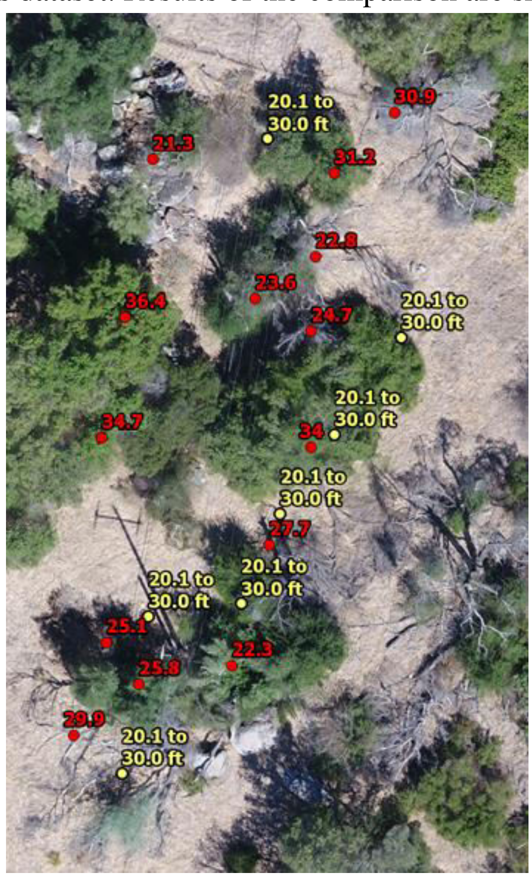


Figure 26. Comparison of Tree Detection Results (red) and SDG&E Dataset (yellow).

It is clear from the above analysis that trees can be detected in a point cloud and provide accurate results. Algorithm A was quite successful in this case, but it is important to keep in mind that deploying it requires performing multiple comparative analyses to find the best parameters for certain types of vegetation and landscape. However, it can be seen as worth the investment as it enables wire sag and growth modeling in the process of hazard detection.

Distance between detected trees and wires

Once the trees are detected, it becomes possible to calculate the distance between trees and wires. PLS-CADD has a built-in layer which contains not only X and Y coordinates of the line but also its height as weather and loading conditions allow.

The analysis team first established the planar distance between points representing trees and lines representing wires. In addition to calculation of the distance, height difference between trees and wires can also be determined by the coordinates. Once the planar distance and height differences are known it is possible to calculate three-dimensional distance in the design as shown in Figure 27 below

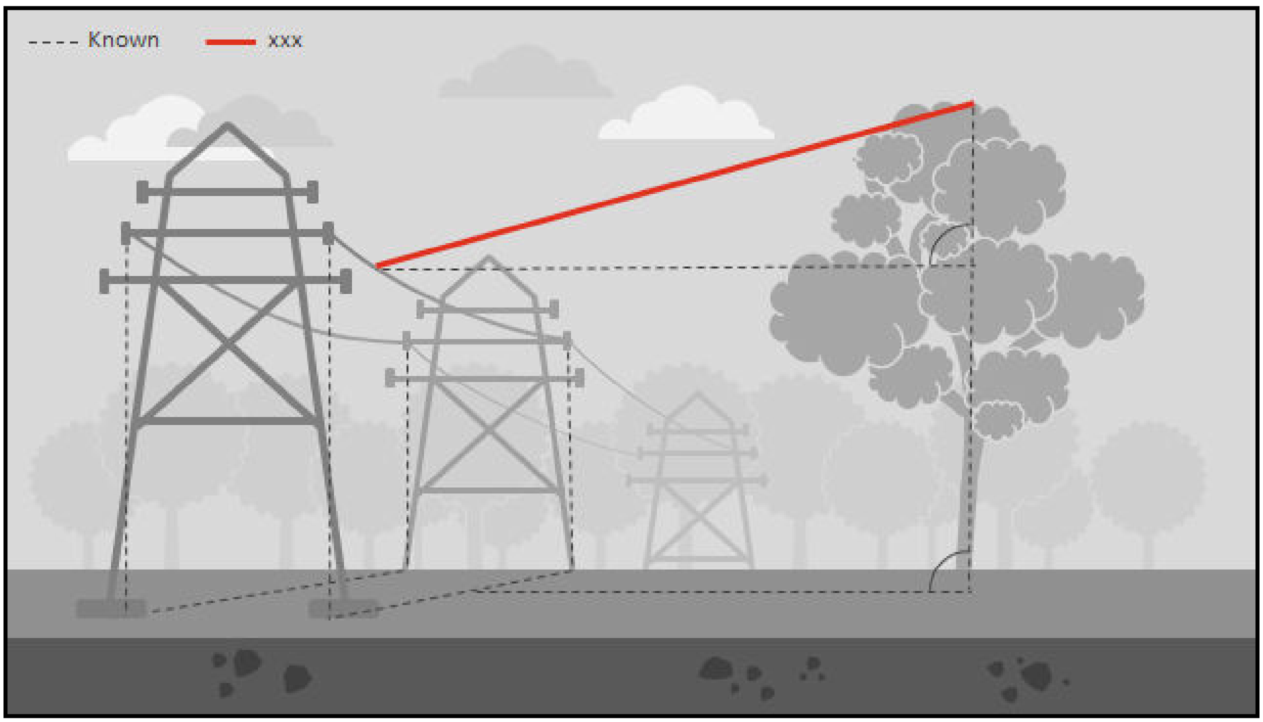


Figure 27. Calculation of the Three-Dimensional Distance between Vegetation and Wire

LiDAR point cloud is classified into categories representing different objects and elements of a landscape. Layered data can be used to measure distance between objects in varying classes. It is possible to measure distance from points located on a tree and points on a wire or a pylon by using point cloud acquired by laser scanner or created from images. Taking into account all of this information and measurements, it is possible to identify the trees that are too close to the infrastructure based on a defined threshold in a colored by class point Cloud LiDAR image as seen in Figure 28 below.

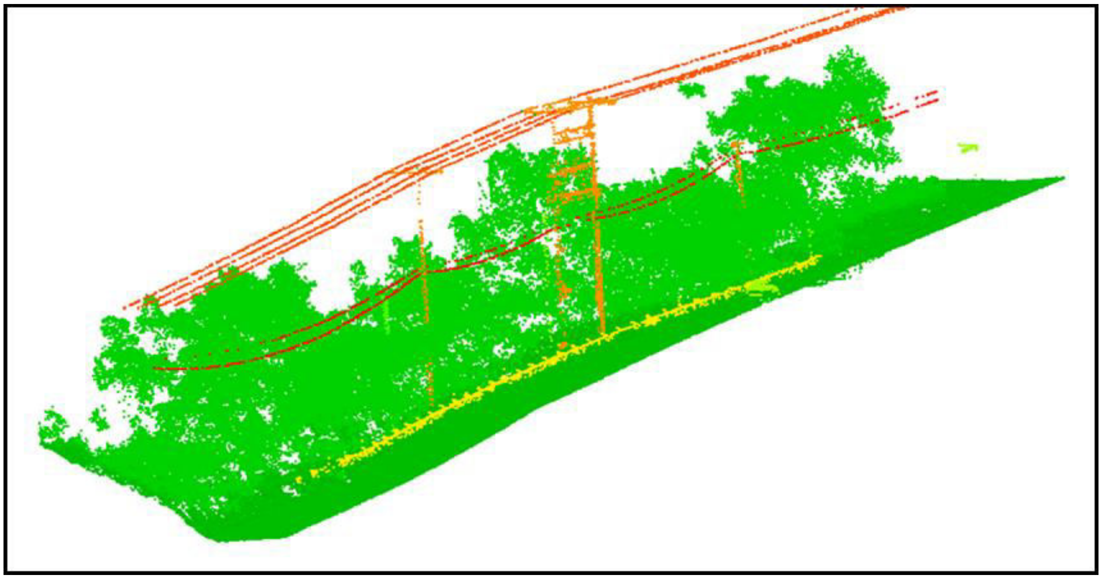


Figure 28. LiDAR Point Cloud Colored by Class

Distance measurements only describe the situation at the time of the measurement (for specific value of the wire sag). Since the sag value is influenced by multiple variables such as tension, loading, or temperature, there is a need to take these changes into consideration. Knowing the situation at the time of the measurement, tension, loading, and temperature maximum change in the wire sag can be defined based on a stringing chart report.

Thin objects like wires may not be well represented in a point cloud derived from images, since the thickness of the wire is relatively small when compared to the Ground Sampling Distance of images. As it often results in gaps in the 3D representation of the wire, LiDAR survey is recommended to collect the data. Since the route of power lines does not vary over time and the only variable that is changing is the sag of the wire, it is possible to use the same point cloud for a few years.

The 3D model of vegetation is reconstructed well on both types of point cloud data, therefore photogrammetric point cloud can also be used for this purpose. Since the structure of vegetation changes often, data gathering should be more frequent. It is possible to merge part of the LiDAR point cloud that represents the wire, with vegetation information from either LiDAR or image point cloud to identify unwanted vegetation. The red in Figure 29 shows the dangerous vegetation that was detected.

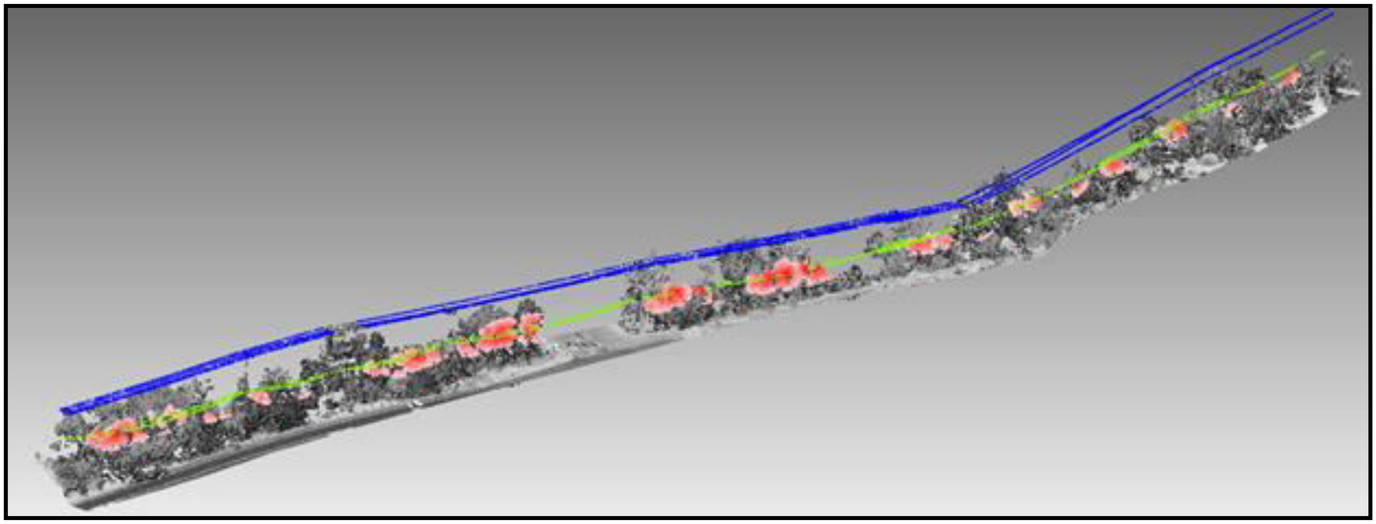


Figure 29. Dangerous Vegetation Detection in LiDAR Point Cloud (shown in red)

Detection of the trees that may affect the infrastructure falling down - Coordinates of detected trees along with calculated planar distance to wires can be used to identify the trees that may be dangerous to the infrastructure. The threshold for identifying hazards is looking for trees whose height is greater than the distance to the wire, and inspecting them for risk and health.

3.2.2.4.3 Additional Features Demonstrated

- Could incorporate species data if it was labeled.
- Fire breaks creation.

Accurate location of wires and poles is critical to identifying areas where trees should be cut in order to prevent fires. The two most suitable approaches are as follows:

1. Usage of point cloud
    - Calculation of the distance between poles and vegetation class is necessary. Once calculated, the distance threshold can be applied to identify the trees that are too close to the poles and should be removed to mitigate hazard.
2. Usage of detected trees and location of the wires represented in a form of vector layer
    - GIS tools can be used to create buffers around poles within a chosen distance. It is possible to count the trees that are within these buffers and export coordinates of these trees to be able to locate them in the field.
3. Numbers represent in figure 28, represent the number of trees to be taken out.

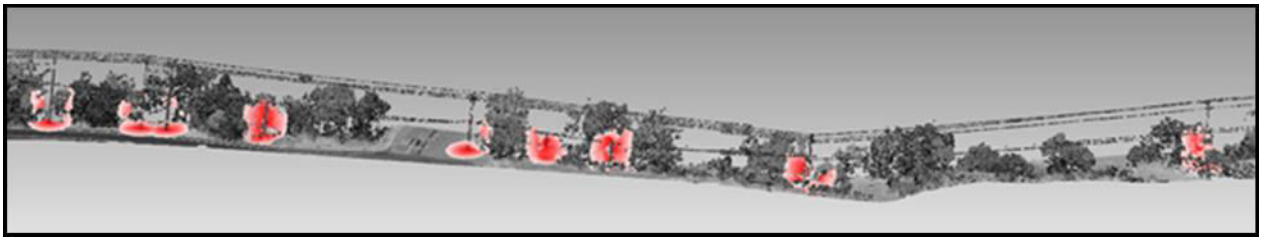


Figure 30. Buffers showing trees within them

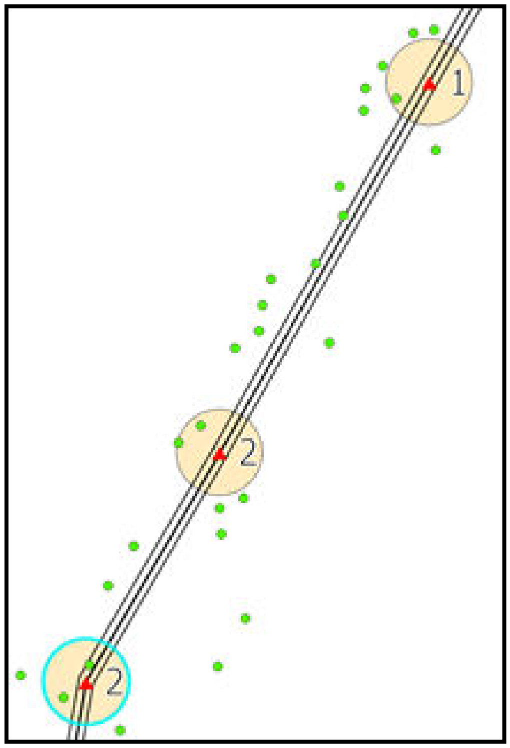


Figure 31. Buffers Around Pylons and Vectored Pylons

3.2.2.4.4 Vendor Recommendations for Future State

Analysis results have shown definite potential for aerial data application in vegetation management. LiDAR point cloud is suitable to perform most tasks. The use case demonstrated that usage of singular classes in the point cloud successfully enabled a direct detection of hazardous areas. As for image point cloud, developing a methodology requires more time due to the complexity of the classification and minimal information about the ground structure. However, once the point cloud is successfully classified and artificial objects (pylons and parts of the wires) are removed, the same algorithm can be used to directly identify hazardous vegetation. Point cloud can identify the trees currently past the threshold, and also identify the trees which may destroy the infrastructure when falling down in the future. In order to utilize point cloud, it is recommended to use DTM obtained from LiDAR and filter out any artificial objects. If using LiDAR DTM, it is important to note that both point clouds must be perfectly aligned. Below are two potential opportunities for UAS data application at SDG&E that were identified by this vendor:

- Investigate value in combined vegetation images with predictive modeling based on tree species growth rates to enable strategic management work-planning; algorithm development can be explored as an option for automated tree species classification.
  - Utilizing an algorithm for tree detection from a point cloud will build an accurate and complete database.
  - An automatic method for distance calculation will enable instant and accurate identification of the trees to be trimmed or removed.
- Investigate the use of near IR imaging to identify trees in poor health that are at risk of falling into infrastructure
  - Aerial data can inform and enhance SDG&E's current data on trees' locations and GIS layers of infrastructure.
  - Photogrammetric point cloud is particularly useful in detecting trees, and can be used to not only accurately detect the location but also the number of trees in SDG&E's vegetation dataset.
  - Photogrammetric point cloud can also provide additional information on attributes of objects (e.g., height of the trees).
- Investigate integration with PowerWorkz system.
  - Integration can drive efficient work-planning while leveraging existing platforms.

The following proposed UAS application will improve the workload on the Vegetation Management teams and minimize the field work that has to be performed. Distances calculated based on the point cloud will be more accurate and can be utilized to measure trees at any height of choice. Long term, the calculations and measurements can be repeated or improved without conducting field trips.

3.2.2.5 Comparison of vendor results

Table 10. Vendor Results Comparison

Vendor	Encroachment Identification	Buffer Zone Shape Utilized	PLS-CADD Sag/Sway Ability
Vendor A	Positive	Rectangular	Negative
Vendor B	Positive	Tubular	Positive
Vendor C	Positive	Tubular	Positive
Vendor D	Positive	Distance Parameters	Negative

3.2.3 Cataloging and Remote Asset Management

This section describes in detail the results for the test case defined in Section 2.5.3 above. The remainder of this section will discuss the approach, results, recommendations for a future state presented by each vendor and a comparison of vendor results.

3.2.3.1 Vendor A Results

3.2.3.1.1 Approach

For this test case Vendor A ingested from the baseline data set and vendor collected UAS data various forms of data including Esri GIS, Shapefile (SHP), LAS, imagery and more. The data sets were organized in an enterprise IDMP and loaded to the vendor tool to allow users the ability to access, visualize and analyze the data. The Vendor A Tool demonstrated the following product features:

- Asset on-boarding through shapefiles and as-built DXF.
- Data ingestion of as-built LiDAR, RGB/IR/video archives and orthoimages.
- Data sorting and association based on metadata.
- 2D/3D visualization with 3D click and display.
- Collaboration tools for comments, annotations, uploads and downloads.

3.2.3.1.2 Results

The Vendor A Tool successfully ingested data from different sources and associated imagery and metadata to SDG&E assets for remote viewing and analysis.

The platform features 2D home, 3D review workstation, reports and data ingestion pages for users to perform various forms of analysis, measurements, annotations and data transfer functions. It includes navigation and controls for here location, zoom and full screen display.

The home page displays a low-resolution background with symbols for various assets and advanced analytics notifications. Selected assets display any desired attribute information and a link to review the asset in the 3D workstation if applicable. This page also provides a summary for inspection notifications that can be tied to the appropriate work orders and allows specific layers of data to be toggled off and on as shown below.

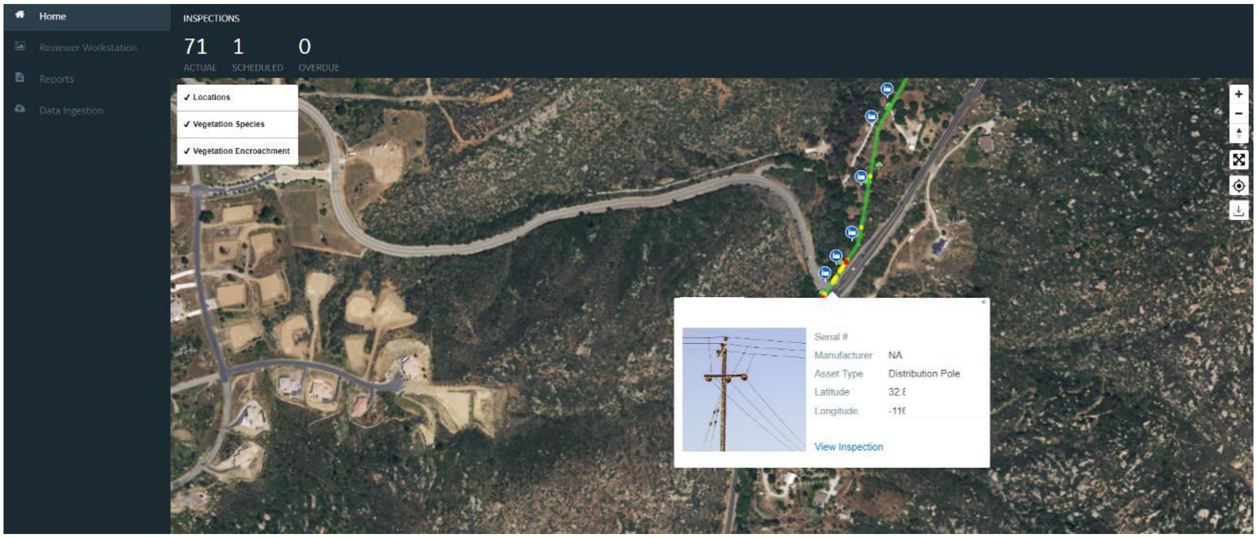


Figure 32. Example of Vendor A Home Screen

The review workstation provides 3D workspace for analysis of metadata, LiDAR and imagery. It includes a hierarchy structure for client, site, asset and date for filtering and selection purposes. There are tools for navigating views, selection of objects and measurement tools such as distance, height, area, volume and more. Users that select a point in the LiDAR cloud or a specific asset will be shown all images displaying that specific point in 3D space. Users have the ability to toggle on and off annotations and specific LAS point cloud classifications, adjust camera position and change other view settings.

3.2.3.1.3 Additional Features Demonstrated

Vendor A also demonstrated addition features such as those identified below:

- The baseline data set was added to the Vendor A Tool as an additional project for visualization and analysis but was not integrated with UAS data collected by the vendor for change management or comparison purposes.
- Images contained in an analytics query result were identified with a flag in the corner, i.e. avian cover detection.

3.2.3.2 Vendor B Results

Results for Vendor B included in Section 3.2.5 below

3.2.3.3 Vendor C Results

3.2.3.3.1 Approach

3.2.3.3.1.1 Upload and configuration processes

Data supplied from the various sources required review, post-processing and transformation before upload to the online system was possible. The following lists each data type and the work undertaken to create suitable outputs for ingestion into the system.

Ortho-rectified imagery (stock, where available) - No further work required. Conversion of 622 ECW (≈700 MB) into a proprietary format optimized for internet streaming (especially important over variable connections).
Time to convert: 60 minutes (automated process).

LiDAR Point Cloud: Required exploration in order to make robust assumptions on the classification schema, the accuracy and suitability of the classification and any filtering that may have been undertaken. Required conversion to a format that was optimized for streaming over an internet connection.
Conversion of LAS into Compressed Point Format – 12 GB.
Time to convert: 30 minutes

Digital Terrain Model (DTM): There is a need to convert and smooth the high-Resolution corridor DTM derived from the LiDAR with low resolution terrain data derived from a third party. This is to enable the fusing of the contextual terrain outside of the narrow powerline corridor. In this case, the ground points from the point cloud were used to create a DTM which was then fused with terrain from the Shuttle Radar Topography Mission (SRTM) elevation dataset.
Time to convert: 30 minutes

PLS-CADD Exports - PLS-CADD can produce an extensive collection of reports and network analytics. Certain features, such as conductors at a given loading and weather condition, can be extracted on demand and then formatted such that it enables display on the online system. For this dataset we were instructed to assess the following factors:

- Vector information - Extract wires from PLS-CADD at different conditions.
- Max Op. (167 °F)
- Blowout (85 mph)
- Vegetation reports
    - Grow in @ Max Op.
    - Grow in @ Blowout
    - Fall in @ Max Op.

Time to extract: 45 minutes
Time to convert: 20 minutes
All data was compiled then uploaded directly to the system database and data store in a batch process. A quality assurance process was then carried out to ensure data had translated correctly and was suitable for display in the system.

3.2.3.3.2 Results

The figures 33, 34, 35, 36 and 37 show a virtual tour of the available data in the online viewing system to provide context as to the extent, detail and cartographic methods of representation.

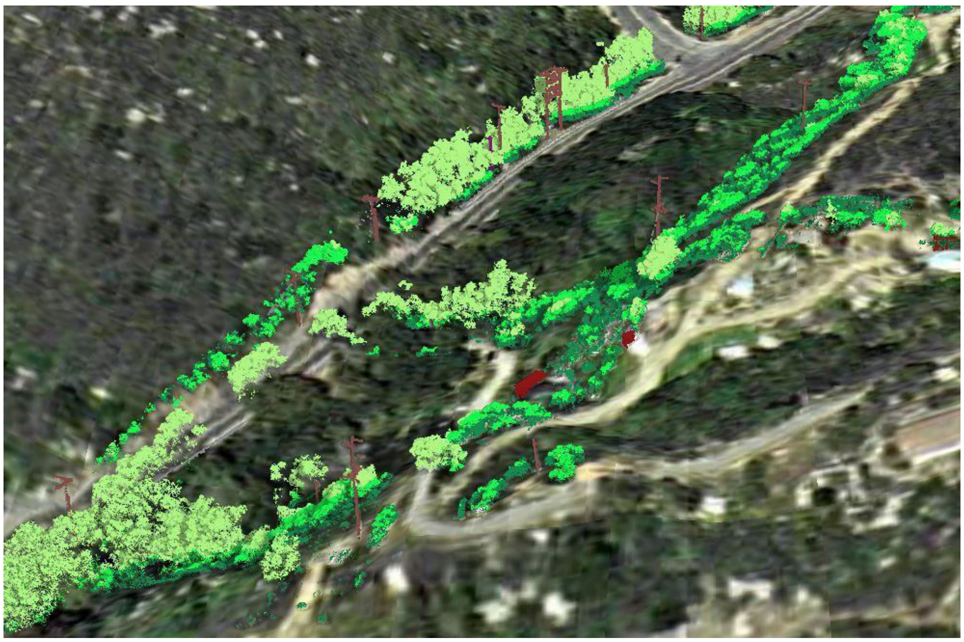


Figure 33. Feature Coded LiDAR Derived From UAS

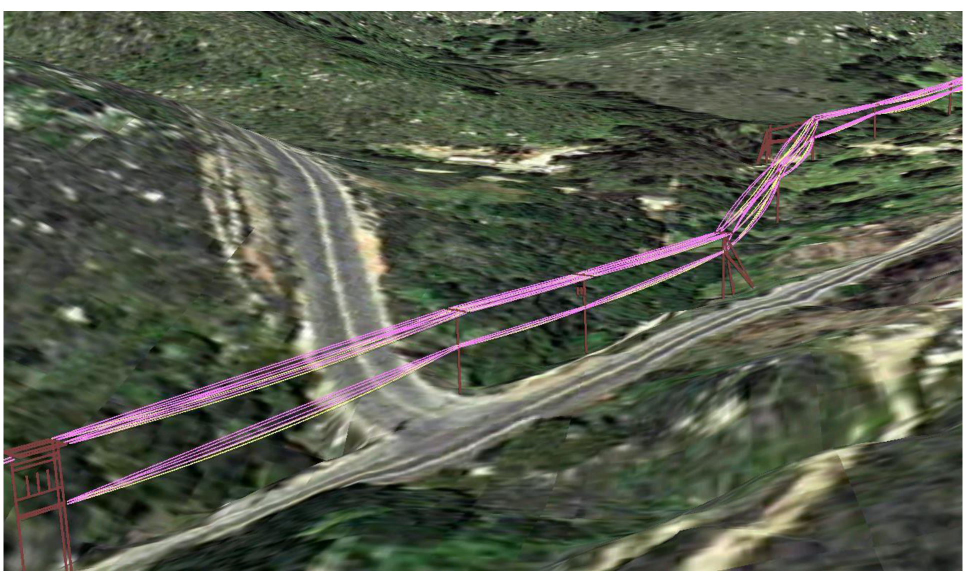


Figure 34. The supplied vectors from the PLS-CADD model.

Note the display of both ‘plumb’ and ‘blown’ conductors, i.e. still air and sagged/swayed conductors under the engineering criteria described earlier

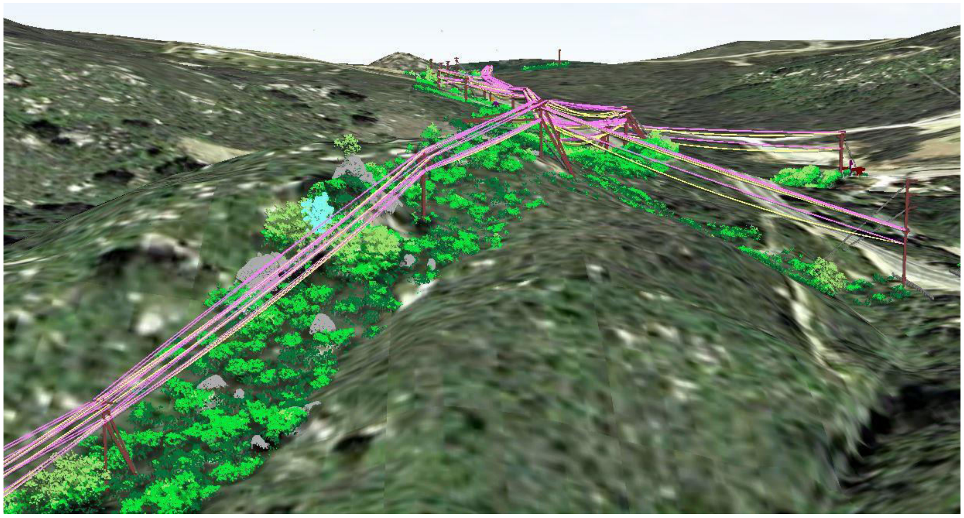


Figure 35. UAS LIDAR Alongside Extracted CAD Model.

Note the contextual terrain data integrated to the more detailed LiDAR-derived terrain.

Figure 36. Oblique UAS Image

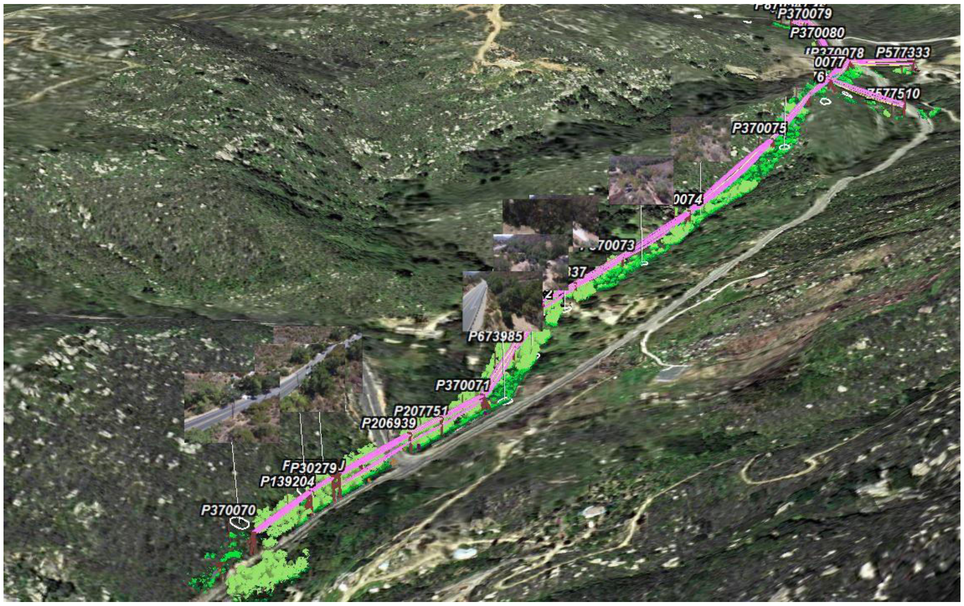


Figure 37. The UAV-Derived Structure Images

3.2.3.3.3 Vendor Recommendations for Future State

- Standardization of data structures and formats to enable more efficient sorting and loading
- A greater consistency in the UAV imagery in particular
- Metadata files giving an overview of the available data and its spatial extents (including areas such as the point classification schema)

Vendor C also provided recommendations for future use cases including:

3.2.3.3.3.1 Data & system integration

The work undertaken showed how the ability to display disparate sources of data (being LiDAR, models and images) can add value in terms of improving access to information for planning and other benefits. Further benefit could be realized by:

- Exploring the options for live-linking GIS and asset data on a read-only basis to ensure that those using the 3D platform could have access to more detailed attribution and up-to-date information.
- Looking at the ways in which users can interact with the 3D environment and start to feed changes and updates back to the connected asset and work management systems, using the virtual environment as the user interface for work recording.
- The expansion to start taking on a greater range of external data sources – taking in new line designs, models from other Computer Aided Design (CAD) systems, GIS data from state and other open sources and a greater depth within the existing corporate GIS.
- The exposure of the online system to external work contractors and other authorized parties such that they have access to more relevant information to enable them to better carry out maintenance and construction tasks.

The benefits in this case stem from the removal of a requirement to access multiple systems to get information or complete a task and the improvement of information provided to those working on the physical network. The means by which this could be tested and validated is through a series of pilot tests which focus on specific user cases (such as integrating the internal vegetation work management system to the online viewer using UAS-derived LiDAR infringements).

3.2.3.3.3.2 Exploring future asset management opportunities

The data used in the trial and the capabilities provided by the online access platform provide significant future potential for asset management. In no specific order are a range of areas that could be explored in future work:

- Dynamic visualization of status per span via cartographic methods (i.e. color according to category) – including last inspection, ground clearance, vegetation status, asset type, risk rating, etc. Enabling reviews of lines and areas to criteria of interest to form an intuitive assessment or enable work planning.
- Virtual line patrols on images and LiDAR for features of interest – then targeting ground patrols directly to areas of interest/concern. Could include vegetation management (including fall-in trees), areas with a greater risk of public safety or assets with certain attributes, enabling the access to all key datasets and records.
- Ground and building change detection to identify potential network risks or change to safety status based on hard object encroachment – showing the location and then enabling assessment from the desktop.
- Connection to investment and asset maintenance optimization platforms based on access to the results of analysis, third party data, internal data and a range of criteria.

3.2.3.4 Vendor D Results

3.2.3.4.1 Approach

Traditionally, geospatial products have been seen as supplementary tools that aid asset inspections on an ad-hoc basis. However, technological advancements have enabled the incorporation of aerial data (e.g., images, photogrammetry, LiDAR), turning geospatial products into a source of reliable and accessible information for companies' comprehensive asset management platforms. Drone based solutions accelerate the processes of inventorying and creating digital asset registers, improves situational awareness of power grid assets, and enhances prediction and reaction capabilities to events that may interfere with the network performance. Asset management typically requires RGB cameras to produce raw photos, point cloud, and 3D models.

The analysis team used aerial data collected during drone inspections over energy lines located in California. The data received from SDG&E consisted of raw images, LiDAR data, and additional vector GIS and CAD data. These were used to develop:

- DSMs and DTMs (from both image and LiDAR data).
- RGB orthophotomap.
- LiDAR reflection intensity orthophotomap.
- PDF files with additional information related to examine assets (attached in Vendor D Tool to relevant dataset).

Due to its features and characteristics, the Vendor D Tool was chosen as a proprietary aerial data platform for the study.

The Vendor D analysis team reviewed utility company leading practices and analyzed ways in which geospatial products enhanced asset management processes. The team concluded that utilizing digital maps of a company's operational radius is the best way to aggregate and visualize multiple sources of data concerning linear utility assets. Adding aerial data to digital representations of governed assets enables companies to retrieve information related to the assets more accurately and efficiently. This not only improves inventory processes but also facilitates asset maintenance in terms of necessary repairs and restorations.

3.2.3.4.2 Results

The Vendor D Tool successfully ingested data from different sources and associated imagery and metadata to SDG&E assets for remote viewing and analysis. The platform features 2D home page, with buttons to switch to 3D navigation and select projects, analysis tools for users and navigation controls.

The home page displays an overall low-resolution background with high-resolution orthophotomap along the test segment corridor. There are dots representing different assets with labels for identification, e.g. trees are labeled with a green dot and the type. The navigation controls include north orientation of screen, split screen view, zoom and navigation history. The tools for analysis include layer controls for all the types of data ingested from the baseline data set. Tools for measurement include distance, area, height, height difference, volume and coordinates. Different icons represent different file attachments and the associated data is displayed when the icon is selected. Figure 38 is an example of Vendor D's home screen.

Figure 38. Example of Vendor D Home Screen

There are also tools to add a note or attach a new file as shown in figure 39 below:

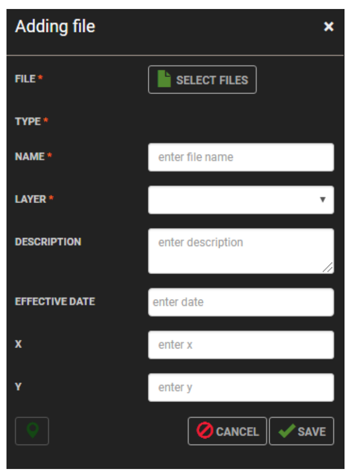


Figure 39. Example of File Attachment Screen

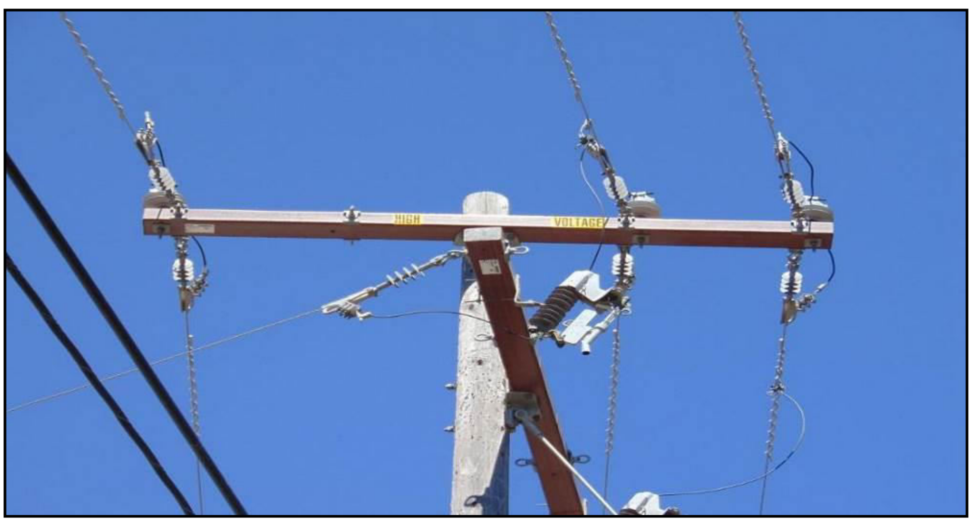
3.2.3.4.3 Additional Features Demonstrated

- Orthophotomap created from RGB nadir imagery for high resolution background.
- PLS-CADD model represented from DXF export included in baseline data set.
- Displayed oblique images taken for pole documentation purposes during baseline data set acquisition.

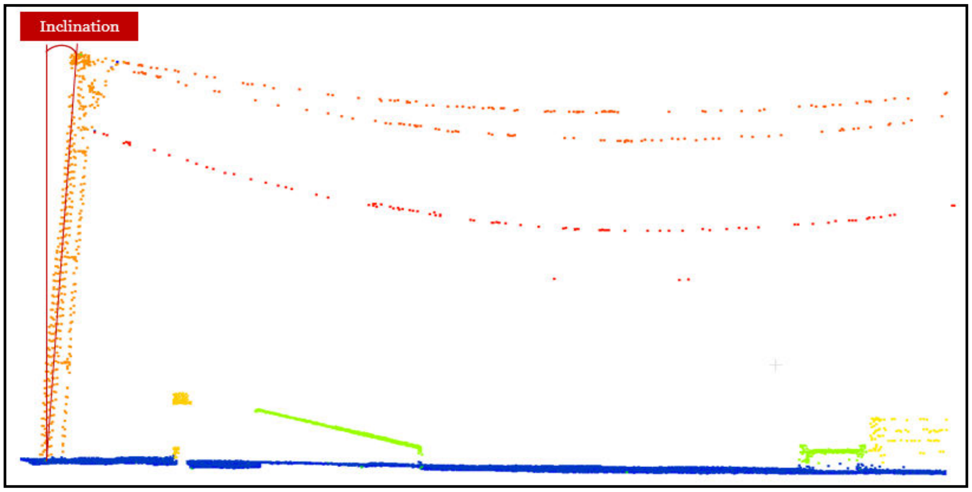
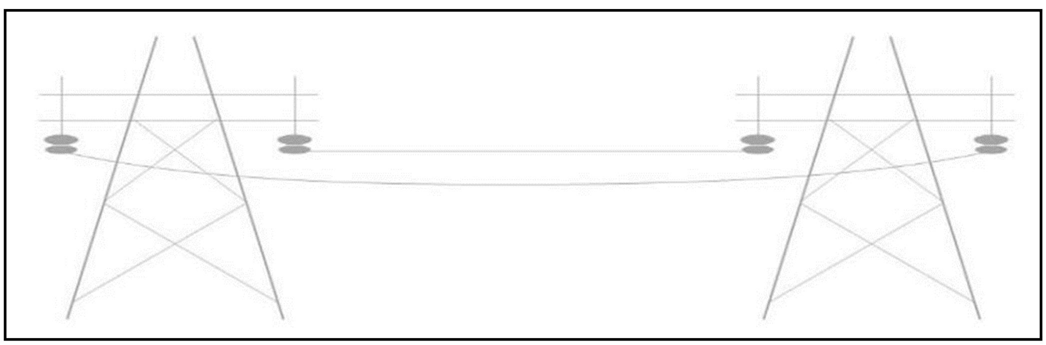
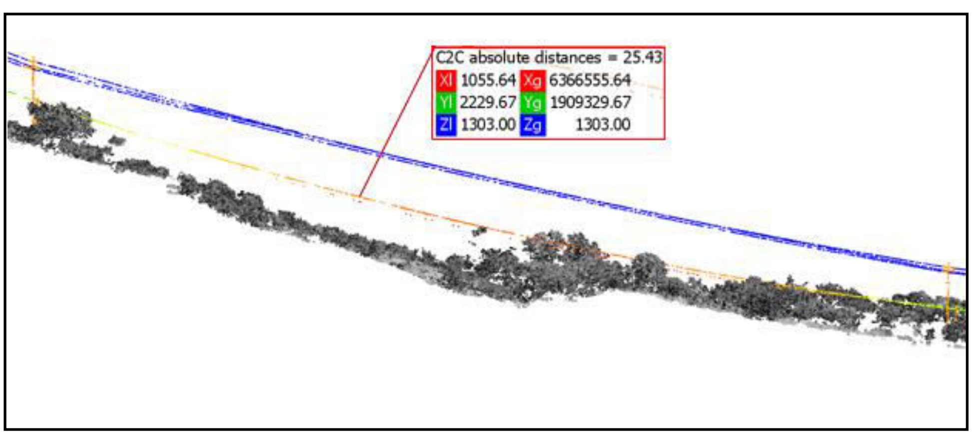
Additional applications of UAS data in terms of asset management and related maintenance proposed by the vendor are as follows:

Table 11. Additional Applications of UAS Data For Asset Management

<table>
<tr><th>Application</th><th>Suitable Geospatial Product</th></tr>
<tr><td>Cataloging assets, verifying quantity and location of inventor or mounted elements
Examples:
Analyzing vectored paths of wires to detect areas where avian covers are needed
Combining buffer and intersect tools to automatically detect areas where problems may appear
Manually measuring problem areas on oblique images or LiDAR point cloud</td><td>Raw photos
Point cloud
3D model</td></tr>
<tr><td>Performing visual assessments to evaluate condition of:
Pole structures (e.g., concrete losses, condition of welds, rivets, coating)
Support structures



Insulators and wires (e.g., wire fixings on the poles)
Oblique image presenting top of the distribution pole including elements such as avian cover, wire fixings, and insulators</td><td>RGB/IR photos and videos</td></tr>
</table>

Controlling the position of a pole relative to the ground by measuring deviation from the vertical position and identifying abnormalities in construction to prevent poles from falling over.  **LiDAR point cloud presenting position of a distribution pole relative to the ground**	• Point cloud • 3D model
Performing wire sag analysis to enable efficient wire transfer of energy.  **Visual representation of wire sag**	• LiDAR
Automatically calculating the distance between SDG&E 2nd level and 3rd level wires or/and third party wires.  **LiDAR point cloud presenting two types of SDG&E wires and one third-party wire**	• Classified LiDAR

Gathering data on the condition of energy power lines in case of natural disasters. Helpful in identifying damages, planning repair services, and mapping current state of natural environment  **Image representing conditions on the ground**	• Orthophotomaps
Creating and enhancing information database for asset data. If the location of a particular pole can be determined by the user on the digital map in the asset management platform, related PDF files with additional information on such asset will be available in the same place for users from different departments to utilize.  **Example of asset information represented from a database**	• PDF files (as a non geospatial product)

3.2.3.4.4 Vendor Recommendations for Future State

Broad use of geospatial products based on aerial data can provide SDG&E with objective and reliable information related to governed infrastructure. Below are recommendations that will enable streamlined daily operations and crucial business processes connected with asset inventory and maintenance:

- Adopt aerial data lifecycle governance framework.
    - Adopting the framework can:
        - reduce duplicates among documentation and databases related to the same asset,
        - fill the gaps in the system related to certain assets or areas of interest,
        - enhance work orders for maintenance purposes with actual images of particular devices to be replaced or inspected manually, and
        - support asset history with objective aerial data evidence to track faults and outages for service restoration and reporting purposes, which ultimately increases overall energy network reliability and responsiveness of maintenance teams.
    - Elevated level of internal situational awareness can drive improved Key Performance Indicators, savings (e.g., prevention of costly breakdowns) and translate into higher customer satisfaction.
- Adopt Vendor D Tool.
    - In order to streamline internal processes connected with asset management and governance over critical energy infrastructure, SDG&E needs a technically robust and universal platform to effectively fulfill their daily tasks.
    - Vendor D Tool integrates functionalities tailored to requirements of a given industry or developed in collaboration with a particular client – In SDG&E's case, it can analyze and present 3D point clouds from LiDAR or photogrammetric images.

3.2.3.5 Comparison of vendor results

All vendors demonstrated the ability to ingest UAS data including RGB imagery and LiDAR and display them in their individual platforms for user visualization and inspection. Each vendor also demonstrated the ability to ingest various types of metadata provided by SDG&E stakeholders and then catalog those assets and tie them to related imagery and LiDAR for user analysis.

3.2.4 System Setup and Integration with PLS-CADD and GIS

This section describes in detail the results for the request to provide a plan for integration with PLS-CADD and GIS. The remainder of this section will discuss the approach, results, recommendations for a future state presented by each vendor and a comparison of vendor results.

3.2.4.1 Vendor A Results

3.2.4.1.1 Approach

For this POC Vendor A approach was to ingest PLS-CADD and GIS data types from the baseline data set to a potential IDMP structure and show how it would integrate with the Vendor A Tool and user interface platforms like GIS and PLS-CADD.

3.2.4.1.2 Results

3.2.4.1.2.1 GIS Integration

Vendor A was successful in demonstrating POC that GIS data sets could be ingested to a IDMP and loaded to the Vendor A Tool for cataloging, visualization and analysis. Although there was not an attempt to integrate with SDG&E GIS, the vendor ensured the ability to provide live updates import/export with Esri GIS databases as needed in a future state.

3.2.4.1.2.2 PLS-CADD Integration

Vendor A did not have the ability at the time of this report to fully integrate with PLS-CADD. The POC covered the LiDAR data file ingestion process, mostly as it related to feature code extraction for the purposes of vegetation encroachment analysis. LiDAR data was presented in the Vendor A Tool to show that LiDAR and DXF data could be readily viewed and queried in their platform but it could not currently ingest and disseminate those files from the PLS-CADD model. Vendor A proposed the standard process for PLS-CADD data ingestion below:

3.2.4.2 Vendor B Results

3.2.4.2.1 Approach

Vendor B did not perform this task but made recommendations as stated in Section 3.2.4.2.4 below.

3.2.4.2.2 Vendor Recommendations for Future State

3.2.4.2.2.1 GIS Integration

GIS represents one of the key operational systems that must interact with the asset management system. Primary interactions between asset management system and GIS could include:

- Supporting mission planning by accessing the GIS data representing the distribution infrastructure to create/update flight plans.
- Automatically tagging assets on ingest with GIS information such as asset IDs and other basic metadata (similar to the workflow demonstrated in the data management test case except deriving the information directly from GIS).
- Inserting hyperlinks to specific images of assets in the GIS data records, allowing seamless access to current and historical images of assets from within the GIS. The platform facilitates downloading the asset data, that can be used in GIS, as the formats are OGC compatible and universally consumed by all geospatial applications.
- Creating workflows to update GIS assets with information derived from analytics.

- Integrating image analytics as tasks directly within GIS.

One or more common OGC data access standards, including WMS and WFS, can also be used to share information between systems. Specific Application Programming Interfaces (API) will need to be created to populate and maintain links between the GIS records and the asset management solution.

3.2.4.2.2.2 PLS-CADD Integration

To support the engineering design workflow, further research is required to determine how PLS-CADD and the asset management system can be integrated to manage the LiDAR data collected by UAS as well as other LiDAR systems.

The general workflow includes:

- Accessing data in the asset management system from PLS-CADD to create engineering backup (BAK) files
- Saving and managing the BAK files in the asset management system
- Generating vegetation encroachment and other analytics such as joint use studies from PLS-CADD's BAK files

3.2.4.3 Vendor C Results

3.2.4.3.1 Approach

The approach of Vendor C for this POC used the rationale that the principle in this use case is access to timely 3D information describing the network location, condition and context, via a suitable platform that may integrate effectively with existing utility systems and processes. The need for such a platform has been recognized by network operators for the following key reasons:

- The GIS platforms in place, while still relevant and crucial to business-wide operations, were designed to provide a detailed and highly controlled single source of records and were often linked to the network connectivity models. The result of this locked-down structure and strict governance is a highly inflexible structure and a slow process of data ingestion, with limitations in the 3D environment.
- Legacy systems have not kept pace with the significant increases in data volumes generated by new sensors such as LiDAR, such that the storage, management and access to this data is challenging if not impossible, using historical approaches.
- The revolution in mobile computing and data transmission via mobile data networks means new demands from the user base and new opportunities to improve the way field operations are planned and managed. There is not however a means to effectively push this data to such devices and provide the ability to view the bulk 3D data, take measurements and see the recently delivered results of analytics, such as vegetation clearances.
- The volumes of data for long term storage, given the trend towards annualized or more regular capture of LiDAR and imagery, is significant such that utility IT systems are

rapidly exceeded in capacity. This challenge is further exacerbated by the complexity in managing the millions of files and thousands of terabytes of data that are generated by utility line mapping programs.

3.2.4.3.1.1 Objectives and architecture

The objectives of this type of system are achieved by:

- Using a cloud hosted solution – to enable hosting near to the customer (minimizing lag) and in a rapidly scalable environment (generally this means Amazon Web Services, Azure or Rackspace in the closest datacenter).
- A focus on the web browser, such that the use of the system is intuitive and simple without the need for complex installations
- The implementation of high compression rates for data transfer, enabling a rich user experience (i.e. sufficient detail without data loading lag) without the need to excessively 'thin' the data.
- The use of open format databases to enable flexibility in connecting to other sources and tailoring the outputs to each customer, particularly crucial to enable the use of existing GIS information and other asset or process control databases.

3.2.4.3.2 Results

3.2.4.3.2.1 Generic system attributes

Based on user feedback, practical experience and the understanding of the network operator in this case, the following are implemented to realize the objectives:

- Inside the portal a 3D representation of the network is displayed, from terrain and base imagery through to high resolution LiDAR and asset images. These can all be layered up to provide a rich, detailed view of the as-built, as surveyed conductors, structures, vegetation and condition.
- The system is configured to use pre-optimized to allow fast loading, and reduced data volumes to be distributed across the internet whilst maintain the visual quality required for review and condition assessment in the portal. This method was chosen as opposed to the alternative on the fly compression or distributing uncompressed data, as this leads to reduced server load – meaning more users can access the data concurrently, and the amount of data that needs to be handled at any given point, resulting in a smoother user experience.
- The system revolves around a central store that then feeds data into the web viewer, this central store can provide feeds into other systems and vice versa. In a future state the platform will have 2D data layers can be fed into other software like Esri ArcMap, ArcGIS Online, QGIS, PLS-CADD as standard WFS / WMS feeds that are fully OGC compliant. Currently only asset data layers (Imagery, metadata, and GIS shapefile) are downloadable and can be used in other software like GIS etc.

- Conversely, existing feeds can be fed into the system, allowing data to be integrated into the system, bringing everything into one place, maximizing the amount of information available to inform intelligent business decisions. Once again, this includes standard WFS / WMS feeds and a range of tabular database connections.
- Variable user demand (managing peaks) is implemented by the use of a horizontal scaling approach, using automated scripts to initiate new instances and access additional computation to ensure performance does not become limited.
- The vendor also brought up an ability of the platform to create new shapefiles from analytics that can be imported into GIS. This feature was not demonstrated.

3.2.4.3.2.2 Data input requirements

The system, based on its intended purpose, is designed to be the overarching platform that collates, organizes and streams a large variety of datasets to end users within utilities. It is designed to work with a multitude of data formats that get converted into standard stream friendly formats for distribution across the internet. However, when it comes to providing an accurate and user-friendly 3D model of the powerline alongside the analytics results, experience has led Vendor C to develop some specific requirements. This includes but is not limited to the import file formats, data thinning/filtering and the types of geometrics in spatial files. These may not be specific to other industry systems however the principles are likely to be similar.
The common datasets to make a 3D Powerline model for ingestion to the system, and similar systems, are:

- Orthoimagery – georeferenced and mosaicked orthometric photos.
- Digital Terrain Model (DTM) – Generated from a classified LiDAR point cloud.
- Digital Surface Model (DSM) – Generated from a classified LiDAR point cloud.
- LiDAR point clouds – collected from an appropriate aerial or ground-based platform and filtered via point classification.
- Vector features (Wires, Towers, Poles, Cables, Transformers, Disconnectors etc.) – as generated from a PLS-CADD or other CAD format model, according to the analysis parameters required by the project aims (i.e. thermal rating, vegetation).
- Infringement Information – including but not limited to LiDAR points representing ground, vegetation and building infringements according to statutory distances.

Each of these datasets have a variety of options for import, depending on capture methods and the formats that have been used to store the data. For pre-processing, we recommend utilizing Tag Image File Format (TIFF) files for the Orthos, DTM and DSM. The TIFF format allows additional geospatial information to be captured within the file, meaning there are no additional reference files.

LAS data is stripped of most of its "meta" data when loaded into the system for streaming, inside LAS files there is a large number of additional attributes that are unnecessary for visualization purposes, so this is removed. Attributes like scan angle, GPS Time, Flight line, Scanner specification can all be removed from the points before streaming. Instead the only information remaining is the XYZ position of the point, and the RGB value it should be displayed as. For ingestion into the system LAS 1.2 Point Type 3 is preferred, as this includes the RGB values enabling easy extraction and conversion. Other LAS specifications are accepted and can be included within the platform; however these require an additional processing step.

For vector features, a wide range of inputs can be used; it is recommended to use Esri Shapefile or SQLite/Spatialite as this ensures a trouble-free import into the database. Vector features are stored inside a PostgreSQL/PostGIS database which enables fast queries, and the ability to store vast amounts of attribution, while giving us the flexibility of a database for searching, reviewing and updating all within a geospatial aware environment. The tables within the database are then streamed into the platform via WFS, which also provides the flexibility to utilize the WFS feeds within other packages, ArcGIS, QGIS and PLS-CADD.

Vegetation infringement information is extracted from PLS-CADD models or from external analytics comparing the distances between conductor and vegetation. These calculations can then be displayed visually within the system, and styled appropriately to provide additional contextual information. It is important to note that there is a deliberate separation between the analytics and the display of results: the computational requirements, interfaces and software needs are sufficiently different that tailored analytics for multiple projects are best done separately and fed into the generic platform.

3.2.4.3.3 Vendor Recommendations for Future State

The online platform is designed to meet a range of utility objectives and the software effort is driven by the direct requirements of existing and potential commercial users. In this context, being a publicly available document and with the content being generically applicable, it would not be appropriate to share a detailed software roadmap. However, the following are objectives in the short to medium term:

- Enabling the utility user to search among the large number of asset and GIS fields available, to ensure rapid and effective navigation across large continuous datasets – via typed search, data sorting and user type profiling.
- More closely integrating the sources of spatial data and imagery with the network GIS and asset data, via loose linkages/integrations – to facilitate a seamless view across disparate sources of information.
- Align the display, configuration and user interactions more closely with the different use cases, particularly vegetation management and asset management.
- Further improving performance as relates to supported devices, operating systems and the speed of access on less robust data connections.

Longer term:

- Implementing integrations to common asset systems with live communication to SAP, Maximo and Ellipse, among others.

3.2.4.4 Vendor D Results

3.2.4.4.1 Approach

For this POC Vendor D's approach ingested various GIS data sources from the baseline data set but did not provide a plan for integration with PLS-CADD platform or files.

3.2.4.4.2 Results

3.2.4.4.2.1 GIS Integration

Vendor D was successful in demonstrating POC that GIS data sets could be ingested to a IDMP and loaded to the Vendor D Tool for cataloging, visualization and analysis. Although there was not an attempt to integrate with SDG&E GIS, the ability to import/export GIS information was demonstrated. The vendor ensured the ability to provide live updates with Esri databases as needed.

3.2.4.4.2.2 PLS-CADD Integration

Vendor D Tool did not have the ability at the time of this report to integrate with PLS-CADD.

3.2.5 Demonstrate Data Lifecycle Management

This section describes in detail the results for the request to demonstrate data lifecycle management. The remainder of this section will discuss the approach, results, recommendations for a future state presented by each vendor and a comparison of vendor results.

3.2.5.1 Vendor A Results

3.2.5.1.1 Approach

For this POC Vendor A recognized the challenges and complexities of obtaining, processing and incorporating the large dataset types proposed for this project. They proposed a robust enterprise IDMP that provides for ingestion of the data, aided in management of the data and the ability to incorporate that data in the daily business decision making processes. Key to their proposal is a system that:

- Associates the collected inspection data to current systems of record and asset hierarchies to allow analysis and business decision making at a deeper level.
- Effectively manages metadata for facilities and their components to provide advanced search and filter capabilities and rules-based analytics.
- Allows for improved and detailed visualization of data types as they relate to specific assets and provides a detailed and multi-dimensional view of the current state of the asset.
- Assists in providing and managing workflows for the various stakeholders in their varied needs.

- Allows for efficient storage of and access to the most current version of the data.

3.2.5.1.2 Results

The initial focus of the Vendor A was ingestion of large volumes of data and the associated metadata management that would be required. Large amounts of incoming data provide a unique challenge in ensuring the data is properly tagged and can be associated with the desired assets. Vendor A proposed three types of metadata to be analyzed; Embedded, User Created and System Generated:

- Embedded metadata is native from the item being processed, in this case usually EXIF data and other information related to the image.
- User created metadata is defined during ingestion via manual or automatic association to asset hierarchies or the systems of record.
- System generated metadata which is automatically added due to automated processing, for example, processing resulting from application of automated defect recognition software.

The following table shows potential types of system generated metadata:

Table 12. Potential types of system generated metadata

Data Type	Required Metadata	Additional Metadata
Imagery – RGB, IR **Video – RGB, IR**	EXIF Info: GPS Latitude, Longitude, Altitude, Time and Date Stamps	EXIF Info: GPS Satellite info, GPS Version, Image Direction references
LiDAR – (.las)	X, Y, Z Values, Intensity, Return info, GPS Time, Scan Angle, Scan Direction	RGB Values, Point Classification

Once the data has been properly tagged, the Vendor A system will allow the user to perform detailed search, visualization, and inspection capabilities. The inspection interface also allows for additional asset inspection, tagging and the addition of image annotation to aid in reporting and information dissemination. During the analytics phase, metadata was updated to allow for better component detection, change detection and management, and other potential use cases. The resulting knowledge gained would allow the business to streamline workflows and improve inspection, asset management and data management processes.

Ingestion of large amounts of data into this system will require development of data storage policies that maintains various levels of access to data based on business requirements. Vendor A proposed developing data retention based on “Hot, Warm, Cold” rankings. The data ranking would determine the level of data storage and ease of access; data ranked “Hot” would be readily accessible while “Cold” data would take more time to bring it up from archived location. The following workflow image outlines how the data collection and retention workflow might look based on collection and data retention rules.

Vendor A proposed the following “typical user” workflow:

- User logs in to enterprise system and performs a query on a system asset.
- Vendor A Tool queries its database and associated other databases. This query is internal to the could-based platform.
- Query results returned to User.
- If new, unprocessed data is available, import of that data is commenced.
- Initial system-added metadata is created for the contents.
- Data approval workflow is run, in which data is ingested, tagged with additional available metadata and, upon approval by reviewing parties, is released for use by end users.
- System continues to perform analytics to process data, identify features, defects, etc.
- Image analytics are run to determine if additional GIS data/assets can be cross referenced.
- User is presented with the results of the analysis.
- User then reviews any alerts or notifications generated via analysis.
- If necessary, system will launch additional applications for user(s) to process and update relevant files.
- If available, historical imagery is related to new imagery to add to the temporal data repository.
- User performs any necessary updates to as-designed or as-built files. Approval process is launched for revisions.

In summary, Vendor A proposed a browser based platform that allows users to process and review new and previously processed imagery and LiDAR products; this system is linked in various ways back to PLS-CADD and GIS data and systems internal to SDG&E. Machine deep learning and analytics would be performed in the cloud-based Vendor A Tool, providing enhanced workflows and long-term data management solutions necessary to be able to effectively distribute and use such a large amount of imagery and LiDAR data. Better storage, access and analysis of such a data collection will allow the business stakeholders to make better and timelier decisions on time critical business processes, resulting in improved service to the customers and a safer and more cost-effective operation.

3.2.5.2 Vendor B Results

3.2.5.2.1 Approach

The approach of Vendor B for this POC recommended using the Vendor B’s scalable web-based UAS data management platform, upload imagery from the field and transform the data into information that enables users across the organization to quickly locate areas of concern, assess the situation, and make informed decisions.

3.2.5.2.2 Results

3.2.5.2.2.1 Ingesting and Cataloging Data

There are several methods available to ingest UAS data into the Vendor B IDMP, ranging from uploading files to consuming the output of a streaming service, which is most often used with Full Motion Video (FMV). With the emphasis of this POC focused on still imagery**,** two common ingest approaches were used - manually uploading data and using an automated process for an entire data collection.

1. In order to upload a file or set of files, the user must have the appropriate permissions which are managed and authenticated through the data management platform. Using any device that has a web browser, users can select a file and upload it to the system. The user will be prompted to enter details about the asset such as a description, expiration criteria, collection details, or any keyword tags they will be used to associate similar data. If the imagery's metadata contains date, time, latitude, longitude, altitude, etc., this information will be automatically catalogued upon ingest as well.

2. Using an http-based RESTful interface, an automated process can be used to ingest and associate related imagery. For example, in this POC a process was developed that determined each image's GPS coordinates and compared its location to a Keyhole Markup Language (KML) file of pole locations ingested from the GIS. Using these locations, the process identified the pole closest to the image's location, allowing the ingest process to automatically determine and assign a tag to the imagery metadata with the pole id for each image. As a result, users can easily query by pole ID to easily locate all related imagery. See figure below.

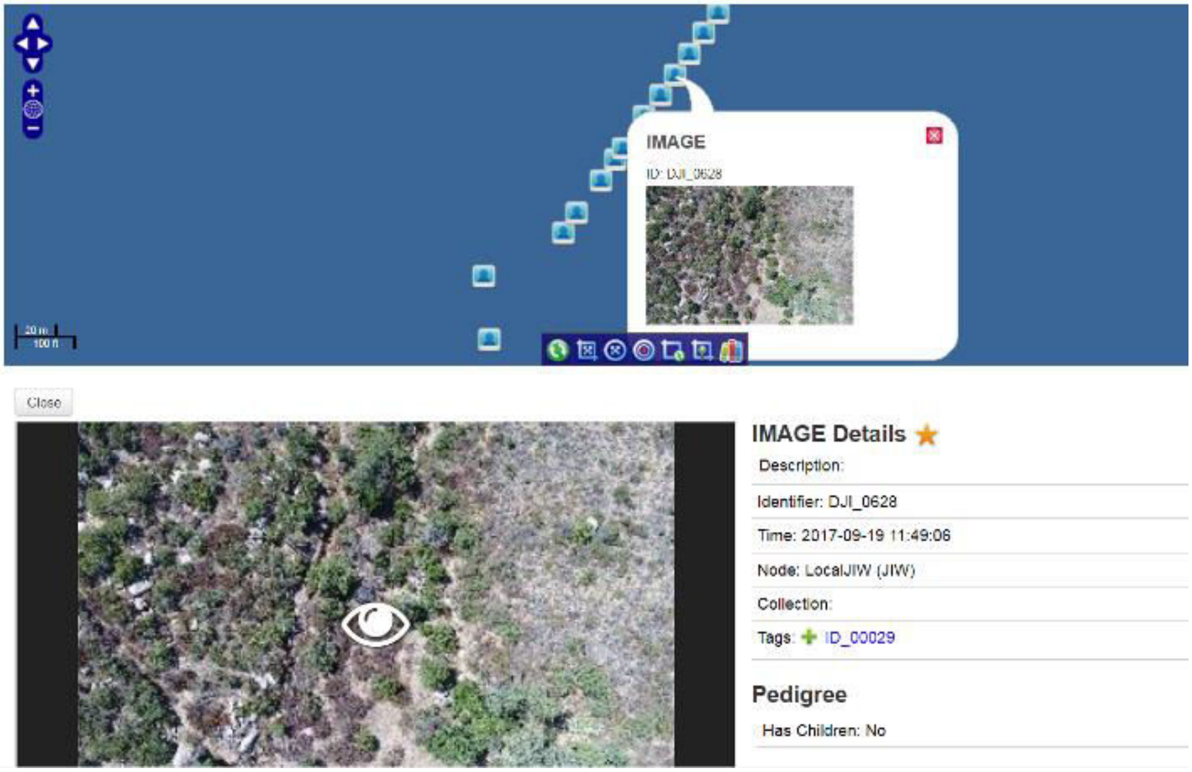


Figure 41. Example of File Attachment Screen

3.2.5.2.2.2 Discovering and Disseminating Data

As utilities capture and consume mass amounts of data, one of the keys to any system is the ability for users to locate data quickly. With Vendor B's UAS data management platform there are several options that can be used to locate assets. They range from entering specific coordinates, drawing a geo-bounding box on a map, or filtering on keywords, platform types, tags, metadata, date and time, or asset types. Additionally, users can either search for specific values or utilize wildcard searches to locate their assets.

Results are presented back to the user grouped by time/start time and ordered with the newest assets first.

A variety of actions can then be performed such as:

- Opening image(s) in image viewer
- Adding assets to a library or workbook
- Executing analytics
- Generating a Google Earth KML file that contains all selected assets
- Downloading the assets to a local machine

3.2.5.2.2.3 Archiving and Deleting Data

Data is automatically archived as part of the ingest process. If the images are processed, the original image is preserved and archived.

To aid in data management there are several techniques for archiving and deleting assets within the UAS data management platform. Three examples of how data can be removed from the system include:

1. Assets can be manually purged by users with System Administrator privileges.
2. An expiration timeframe can be assigned to the asset. For example, if a company policy is to remove data from the system once it reaches an age of five years, an expiration timeframe of 5*365 = 1825 days can be assigned to the asset. Once that expiration period has been met the asset is automatically deleted from the system.
3. The system can be configured to monitor disk space so that when a predetermined threshold of available disk space is reached, the oldest files are automatically removed. System administrators can manage what assets should be considered for deletion, which ones should not be removed, as well as how many days an asset should be retained before it is eligible for deletion.

In the event a delete activity fails, administrators have access to logs that identify the affected files and are provided the ability to flag them for deletion or save and archive the assets.

3.2.5.2.3 Additional Features Demonstrated

3.2.5.2.3.1 Managing Users and Permissions

User access to the UAS data management platform can be managed several ways. User accounts and groups can be configured to use an internal or external Authentication Server or Microsoft Active Directory (using Lightweight Directory Access Protocol (LDAP) queries).
System administrators can also control what specific users can do within the system by setting up Role Based Access Controls (RBAC). RBAC provides administrators with the ability to create roles, assign groups of users within that role, and define access privileges. This process allows administrators to control what types of actions groups of users can take within the system (e.g., restrict one group of users to viewing data while allowing others the ability to read and write data to the system). Figure 42 shows the users role based on access control.

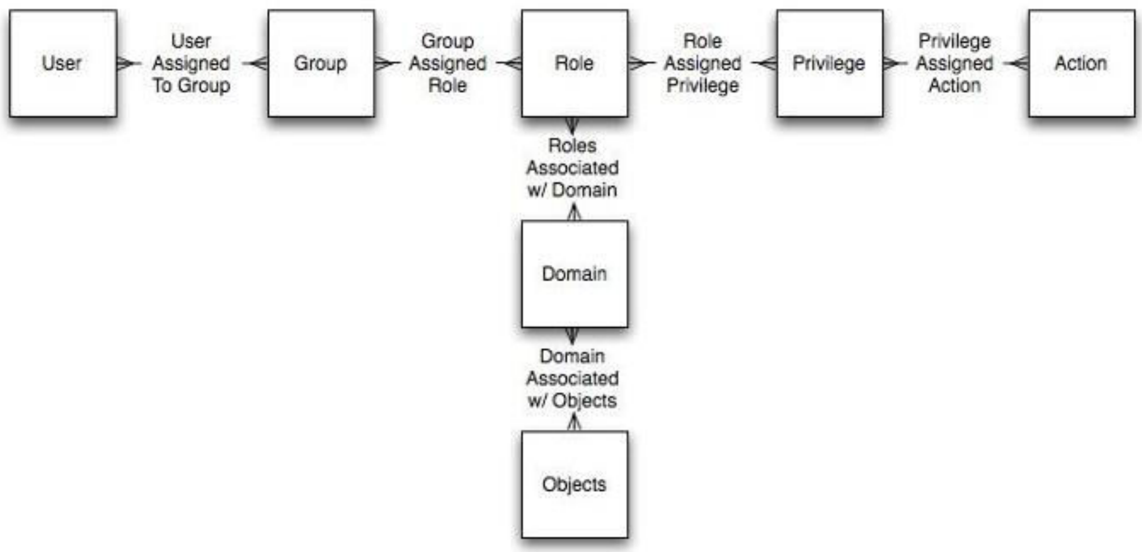


Figure 42. Role Based Access Control Component Diagram

3.2.5.2.3.2 GIS Integration

The Vendor B UAS data management platform and SDG&E's GIS both support OGC data access standards including WMS and WFS. As a result, assets from the UAS data management platform can be downloaded and viewed within the GIS.

Below is a visual representation of assets that are stored in the UAS data management platform which are downloaded and visualized within a GIS. These assets include images which are represented as green triangles and videos which are represented as red airplanes. The platform is currently only capable of integrating the core analytic tools from their remote sensing platform into Esri ArcCatalog toolbox.

3.2.5.2.4 Vendor Recommendations for Future State

While the Vendor B UAS data management platform met all expectations of this test case, the application of analytics to assets in the geospatial and temporal data catalog will require an asset-centric management approach. Vendor B proposed a plan to provide WFS feeds of asset data, that can populate SDGE GIS portal applications.

3.2.5.3 Vendor C Results

3.2.5.3.1 Approach

Vendor C did not demonstrate a data lifecycle management plan but did provide recommendations for future use cases related to data management and ingestion described in Section 3.2.5.3.4 below.

3.2.5.3.2 Vendor Recommendations for Future State

Vendor C also provided recommendations for future use cases including:

3.2.5.3.2.1 Enterprise data management

The project in this instance looked at a snapshot in time on a portion of the network. It is the experience of Vendor C that:

- Much data is collected each year by different groups within the utility.
- This data may not be easily accessible (or in some cases, not widely known that the data exists).
- The data is increasingly becoming unwieldy and difficult to manage due to file sizes and a range of standards and formats.
- There is willingness to do things like machine learning or change detection, but the 'data management infrastructure' has not been designed with this in mind.

Assuming these challenges may be overcome, there is much potential to be found in exploiting and making available a wider set of data to the organization and analytics partners in order to facilitate:

- The detection of topographical and asset changes based on geospatial datasets such as imagery and LiDAR (understanding what is happening around the assets and the Right-of-Way (RoW)).
- The creation of large multi-year training datasets for a range of machine learning applications, by making available the results of raw data, analysis and models to enable training processes to be completed in an automated fashion.
- The ability to start understanding asset degradation and change via the images of those assets, as far back as is needed.
- The ability to go back in time to understand a situation in a given location in cases of liability or understanding early asset failure.

This may be facilitated by designing a 3-tiered data management and access infrastructure, which considers:

1. Raw/bulk data storage – with the input datasets being photos, aerial images, LiDAR, meteorological observations, loading data and so on. This is structured around the topology of the datasets and the networks to enable a logical organization and is managed via automated tools.
2. An access portal to provide visibility to the data location and metadata – showing what is in the store, when and how it was collected and providing direct access. An example of this platform is the Trimble data marketplace, a general toolset based on cloud infrastructure. In particular, this tier is the enabling software toolset that extracts data for analytics process and for the final tier.
3. An access portal for the 'latest cut' of the data, enabling an understanding of the sort of data that does exist and automatically provisioning the most up to date information for the wider user base. A 3D platform, this might also provide a user interface for Tier 2, enabling a more seamless user experience.

This case, which is about enabling infrastructure for some of the more in-depth analysis and applications, is something that could be explored via processes such as detailed data audits, data standards harmonization and test and development of platforms supporting each of the three tiers.

3.2.5.4 Vendor D Results

3.2.5.4.1 Approach

The approach of Vendor D for this POC suggested that in order to manage the various types of gathered aerial data and geospatial products in an efficient manner within the structure of a large organization, it is essential to establish appropriate aerial data governance principles by providing a clear foundation and guidelines. Establishing a framework of data governance starts with defining the concept of data governance.

Data governance is the practice of defining the standard processes an organization will leverage to manage gathered aerial data in support of its operations in an efficient and organized manner. A thorough and effective data governance and lifecycle management strategy addresses regulatory requirements, enables business continuity, and enables collection of necessary data by stakeholder in a timely, cost effective manner.

Exercising aerial data governance across the organization is critical for long-term success, sustainability, and execution of the organization's mission. Such transformation requires a strong foundation in each identified component of aerial data governance.

Successful facilitation of aerial data governance requires a cross-section of people, data and technology. All three elements play a crucial role in enabling effective usage of aerial data across the organization.

3.2.5.4.2 Results

Once the data governance policy has been defined and put into place, Vendor D sets out what they feel are necessary pieces in the data lifecycle management process. The following outlines the steps they see in this process, their evaluation of the current state of the process at SDG&E, and any recommendations they see that would help improve the overall process:

- Tasking – Defining the requirements for the type of data to be collected and employing either internal or external assets as necessary to facilitate the data collection.
  Currently Vendor D feels SDG&E has limited standards and documentation on collection and dissemination of aerial data. The following steps are recommended for improvement of standards on handling data:
  - Development of guidelines based on data and operational needs
  - Establishing a list of use cases across all departments and stakeholders.
- Collecting – Imagery, video, or LiDAR is captured using the appropriate system and delivered for processing to be applied to the user's use case.

Currently SDG&E possesses a good set of risk and safety policies regarding aerial data collection, whether by internal company assets or external vendors.
Recommendations –
  - Development of an SOP defining when to use internal or external collection resources based on cost-benefit.
  - Develop SOP defining technology requirements for data collection.

- Processing – Conversion of the raw data into usable data products and stored in accordance with the data governance policies in place.
  SDG&E has limited capabilities for processing data products in-house.
  Recommendations –
  - Develop SOP that details the cost-benefit analysis for in-house versus external processing and includes specifications for processing data, either internally or externally.
- Exploiting – Performing analysis and extraction of value-added and relevant information required to support the use case in question or the key stakeholders in their daily work.
  SDG&E currently uses PLS-CADD and Esri GIS software to display and analyze GIS, CAD and collected aerial imagery products.
  Recommendations –
  - Development of web-based tools and analytics that will assist in processing collected data for use in defined business cases.
  - Development of an SOP for data analysis.
- Disseminating – Ensure the data, analysis and results are shared among the stakeholders in support of the business decision making processes.
  SDG&E currently uses ineffective measures to transfer and share collected aerial data products, usually Electronic Data Transfer, File Transfer Protocol (FTP) or physical devices (thumb drives or portable hard drives). While they possess security policies and technological capabilities in terms of hardware and software that provides adequate guidance, they lack the additional policies and storage media to effectively incorporate regular use of aerial data products.
  Recommendations –
  - Document current policies for working with aerial data.
  - Develop a centrally managed platform for ingestion, storage and analysis.
  - Develop a storage and maintenance SOP
  - Develop a data retention policy

Vendor D provides a robust and detailed analysis of the data governance needs and lifecycle management requirements in order for SDG&E to take their collection and analysis of data to the next level.

3.2.5.4.3 Vendor Recommendations for Future State

Transforming the aerial data governance from a reactive level to a governed level is a long-term, continuous improvement effort that requires a transformation roadmap. The following steps are recommended to build a strong foundation for successful data governance within SDG&E:

Aerial Data Governance Recommendations:

- Establish a project management structure around data governance transformation.
    - Define clear roles and provide strong backing and sponsoring from the executive level.
    - The steering committee should have a holistic view over the process.
    - Data stewards should be established in order to effectively control aerial data governance progress and usage across departments.
- Identify and quantify the opportunities and benefits that aerial data bring to the organization.
    - Consider the savings it enables, especially compared to current processes.
- These benefits must be regularly and repeatedly communicated to all stakeholders.
- Develop aerial data governance strategy.
    - Based on deep assessment of current maturity, the future state of aerial data management capabilities must be established, and a long-term roadmap developed and accepted.
- Develop consistent data definitions, architecture, standards, policies and procedures.
    - Rules and security levels for data usage must be established. All key users should be trained and accountable for the data and metadata.
- Establish metrics and reporting structure to control and gather feedback about the aerial data usage, data needs and requirements across the organization.
    - Milestones and thresholds should be identified in order to measure is the project objectives has been met.

Aerial Data Lifecycle Recommendations:

Tasking Recommendations:

- Identify appropriate organizational leadership to drive program standup.
    - Leadership will maintain momentum and provide the business case for a requirement driven approach that enhances core business activities and maintains regulatory compliance (e.g., federal and state).
- Define internal process for defining and routinely communicating UAS data collection requirements from organizational leadership to operations groups.
    - Supplement with appropriate governance and tools (e.g., PowerWorkz or equivalent) to enable access to current taking and both downward and upward sharing of leading practices and lessons learned.
- Develop guidelines for defining data requirements per operation type.
    - Data requirements will later inform the type of UAS and sensor needed.
- Establish a list of all use cases of aerial data usage across all departments.

    - Prioritize use cases according to technical feasibility (hardware and tools), as well as cost-benefit analysis.

Collecting Recommendations:

- Define and document collection process.
    - Processes that meet leadership defined requirements.
- Determine collection cadence.
    - E.g., How often to fly UAS to meet both regulatory requirements and provide preventative maintenance return on investment.
- Perform cost-benefit analysis.
    - Analysis on performing UAS collection using external sub-providers vs. standing up wholly owned program capabilities
- Define and document process for sending collected data from UAS to appropriate next step user.
    - Both who and how needs to be defined on both ends
    - The collection and receiving teams needs to identify the people in charge of sending receiving and on the method (i.e., physical passing of memory cards vs. leveraging cloud based solutions such as Esri Drone2map, which is compatible with current SDG&E GIS platforms)
- Develop a procedure for conducting collection cost-benefit analysis based on defined criteria to drive future decision making.
    - Analysis will determine which type of operations require in-house or outsourced data collection.
- Develop procedures for defining and selecting technology requirements (e.g., what UAS and sensor types create return on investment).
    - Requirements will inform the type of UAS and sensor needed.

Processing Recommending:

- Define and document process for proper processing.
    - Validate that routine processing aligns with original requirements, that right data type is being captured for inputs, and that outputs enable expected exploitation.
- Identify necessary software solutions (e.g., machine learning).
    - Assess whether these activities she be performed by sub-providers or internally.
- Develop procedure for conducting processing cost-benefit analysis (i.e., what types return value).
    - Analysis will determine the most optimal way for processing depending on the use case and resolution/accuracy requirements.
- Develop procedure for processing data.
    - Define and document the process for each type of data processing to be performed (e.g., categorizing and cataloging images)

    - Include guidelines on properly generating orthophotomaps, 3D point clouds, Digital Terrain Models (DTM), Digital Surface Models (DSM), and list technical requirements for final products.
- Define and document for transferring processed data to end users.
    - End users will receive properly transferred data.

Exploiting Recommendations:

- Define the business activities to be supported by collected data.
    - Include guidance on activities for all types of aerial data and guidelines for properly utilizing all analysis tools to drive efficiencies.
- Develop routine process to assess whether or not data is having desired impact.
    - Process will promote enhancement of data as needed.

Disseminating Recommendations:

- Document all current processes of working with aerial data.
    - Documentation will enable design of new workflow with aerial data processes embedded within.
- Develop centrally managed platform to discover, gather, analyze, and store aerial data. Setup appropriate access for key stakeholders.
    - The architecture and functionalities must be designed together with key users.
    - Provide easy access to all data linked to a certain geographic location so that all stakeholders can easily find and retrieve all relevant information.
    - Facilitate easy integration with other software solutions across the organization via web services such as Web Map Service (WMS), Web Feature Service (WFS) or Web Coverage Service (WCS), common spatial databases, or file systems.
    - Allow integration with Deep Learning models.
    - Design and choice of central data storage must be performed in parallel.
- Develop procedure for data maintenance.
    - If SDG&E chooses to use internal servers, the governing directives for its use should contain detailed instructions for their own employees as well as third-party vendors.
    - If platform will be deployed on the cloud, the governing directives for its use should only include information necessary for SDG&E employees to upload and archive data on the cloud.
- Develop data retention policy.
    - Typically propose an average of 6-24 months.
    - The above average duration of storing data on cloud or server to be between 6 to 24 months. However, period of time should be set during internal evaluation process by analyzing employees needs as well as costs of storing data.
- Perform stakeholder analysis.
    - Analysis will identify key data needs and enable definition of supporting processes.

4.0 Project Outcome

4.1 Key Findings

The tools evaluated in this project were demonstrated in use cases that would improve system reliability, safety and potentially create operational cost savings. Remotely sensed UAS technology when combined with geospatial analytics provides an effective tool for accomplishing some of the key metrics defined in the EPIC guidelines. Vendors successfully demonstrated the following POC analytics:

1. Avian Covers – The use case provided guidance on UAS imagery collection procedure and resolution along with proving machine learning is a viable option to identify and asses T&D electrical assets.
2. Vegetation Encroachment Identification – The use case provided guidance on UAS collected LiDAR data and proved that vegetation and electrical facilities can be measured and modeled with remotely sensed data.
3. Sage, cataloging and management of UAS data - The results of this use case included providing a data management platform for the data collected, applying analytics to answer specific questions, and delivering analytics results to end users.
4. Web-based asset management platform as detailed in this document will enable organization-wide UAS data management which will allow users across the organization to quickly and easily locate critical information to make informed decisions.

The project learning involved understanding the use of advanced analytics on images collected from UAS and other sources that could be used to automatically identify equipment of power lines. The identification and cataloging of assets remotely presents an opportunity to SDG&E and other utilities to undertake cost-effective remote inspections that would otherwise require personnel in the field, driving up costs. It also ensures personnel safety during inspections which could be compromised when inspections are done in treacherous terrains. Vegetation encroachment identification presents an opportunity for SDG&E and other utilities to effectively manage down power lines due to falling trees and effectively estimate the growth of trees in relation to the power lines. Through this demonstration, the project team learned of the wide array of use cases that could be developed to serve multiple stakeholder groups within utilities that are ultimately responsible to provide safe and reliable power to their customers.

4.2 Recommendations and Next Steps

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. The evaluation should also focus on developing requirements for integration of this data management platform into the SDG&E information technology environment. While the project successfully demonstrated the value of advanced analytics using UAS data, additional evaluation is required before operational deployment of the data management platform.

The project team recommends an IDMP architecture diagrammed in Appendix C. This architecture diagram depicts one proposed Data Management Platform (DMP) structure that would provide storage and access to stakeholder platform and data requirements. Other elements to consider include:

- Responsible, Accountable, Consulted, Informed (RACI) matrix for data governance
- A project management structure should be created that focuses on data governance transformation.
- Identify and quantify the opportunities and benefits aerial data can bring to the business.
- Develop a comprehensive data governance strategy.
- Based on the governance and user needs, develop a set of standards, policies and procedures and from that a system architecture capable of managing the data and policies.
- Ensure that metrics are gathered that allow measurement of the program success and the ability to change to meet future needs.
- Data retention policy based on use case needs.
- Develop UAS data collection standards that include image collection specifications for all types of UAS data.
- Diagram existing data management architecture and identify gaps and overlaps for all stakeholders.
- Develop use cases summaries and for all stakeholders.
- Develop user workflows and platform requirements for interaction with vendor tool.
- Develop cost benefit analysis comparing current and proposed processes along with UAS data sources and newly developed collection requirements standards.
- Develop a more accurate risk-based analysis for proactive vegetation management including species, growth rate, health and conditions like weather and wind models.
- Investigate vendor tool bandwidth and browser requirements for field and office end users.

5.0 Technology Transfer Plan

5.1 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, by submitting papers to technical journals and conferences, 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 per the recommendations.

5.2 Adaptability to Other Utilities and Industry

As technology evolves utilities are poised to leverage UAS and other data collection technologies to capture high resolution imagery. In some cases, these images have been stored in silos in different business units within the organizations, used by individual stakeholders for their own purposes. This EPIC project demonstrated the value of having a central repository (data management platform) to store, catalog, and sort data that could be used by multiple stakeholders concurrently. It also allows the stakeholders to perform deep learning analytics on the vast amount of data to provide actionable results to important test cases ranging from auto 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.

6.0 Metrics and Value Proposition

6.1 Metrics

The project metrics used to evaluate and test UAS technology and vendor machine learning tools and software as they related to three specific test cases are listed in Section 3.0 above. In addition to the use cases covered earlier, the following describes additional metrics:

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 report 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 report 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.

6.2 Value Proposition

The purpose of EPIC funding is to support investments in R&D projects that benefit the electricity customers of SDG&E, PG&E, and SCE. The primary principles of EPIC are to invest in technologies and approaches that provide benefits to electric ratepayers by promoting greater reliability, lower costs, and increased safety. This EPIC project contributes to these primary and secondary principles in the following ways:

- Safety – The use of UAS technology enables remote asset management thereby helping utility field crew with tools that promote their safety. During emergencies such as fire or other natural disasters UAS technology can act as a first line of defense in monitoring and tracking remotely, thereby ensuring safety of personnel and limiting harm to people and property.
- Reliability – Greater reliability of systems can be achieved with using UAS and other data collected and running deep learning analytics on the data to identify issues before

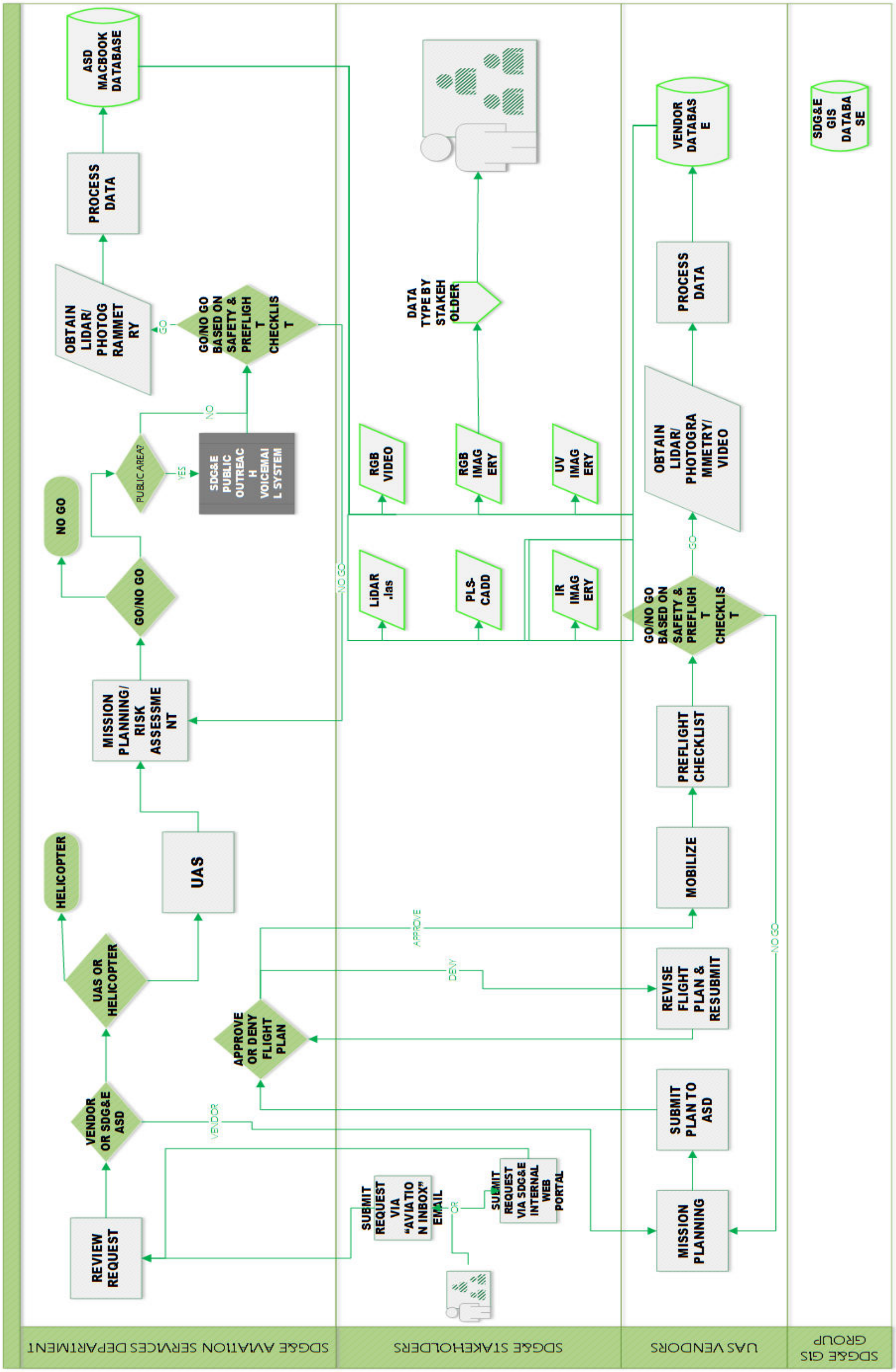
they occur. It also helps various stakeholder groups (e.g vegetation, environmental and other groups in utilities) to effectively plan asset management activities, thereby improving reliability of service.

- Efficient use of ratepayer monies – Asset inspection costs can be reduced using advanced technology such as UAS that complements on field inspections by field crew. Crews can be deployed more effectively and in a cost effective manner, thereby making efficient use of ratepayer monies.

7.0 Appendices

7.1 Appendix A: Aviation Services Department UAS Workflow

Workflow depicting the current ASD process for collection of aerial sensor data.



SDG&E AVIATION SERVICES DEPARTMENT
SDG&E STAKEHOLDERS
UAS VENDORS
SDG&E GIS GROUP
REVIEW REQUEST
VENDOR OR SDG&E ASD
VENDOR
UAS OR HELICOPTER
HELICOPTER
UAS
MISSION PLANNING/ RISK ASSESSMENT
GO/NO GO
NO GO
PUBLIC AREA?
YES
NO
SDG&E PUBLIC OUTREACH VOICEMAIL SYSTEM
GO/NO GO BASED ON SAFETY & PREFLIGHT CHECKLIST
GO
OBTAIN LIDAR/ PHOTOGRAMMETRY
PROCESS DATA
ASD MACBOOK DATABASE
APPROVE OR DENY FLIGHT PLAN
APPROVE
DENY
NO GO
SUBMIT REQUEST VIA "AVIATION INBOX" EMAIL
OR
SUBMIT REQUEST VIA SDG&E INTERNAL WEB PORTAL
LIDAR .las
PLS-CADD
IR IMAGERY
RGB VIDEO
RGB IMAGERY
UV IMAGERY
DATA TYPE BY STAKEHOLDER
MISSION PLANNING
SUBMIT PLAN TO ASD
REVISE FLIGHT PLAN & RESUBMIT
MOBILIZE
PREFLIGHT CHECKLIST
GO/NO GO BASED ON SAFETY & PREFLIGHT CHECKLIST
OBTAIN LIDAR/ PHOTOGRAMMETRY/ VIDEO
PROCESS DATA
VENDOR DATABASE
SDG&E GIS DATABASE

7.2 Appendix B: Vendor-Stakeholder Use Case Matrix.

This matrix depicts the used cases identified by each stakeholder in Section 2.2 above which is cross-referenced with the platforms existing capability to demonstrate the use case as part of this pre-commercial demonstration.

	Stakeholder Use Cases																									
	VEGETATION MANAGEMENT							ELECTRIC DISTRIBUTION PLANNING			ENVIRONMENTAL										LAND MANAGEMENT					
Vendor	VEGETATION ENCROACHMENT ID	CORRECTED LOCATIONS OF CURRENT GIS ASSETS	CHANGE DETECTION ON SUBSEQUENT DATA SETS	SAG AND SWAY CALCULATIONS FOR ENCROACHMENTS	IDENTIFICATION OF PROTECTED VEGETATION AND WILDLIFE SPECIES	USE ASSET METADATA TO PREDICT GROWTH RATES	USE REPETITIVE DATA SETS TO PREDICT GROWTH RATES	ASSET CATALOGING	REMOTE ACCESS	PLS-CADD INTEGRATION	ASSET CATALOGING	AVIAN COVERS	CORRECTED LOCATIONS OF CURRENT GIS ASSETS	ACCESS TO RECENT IMAGERY VIA GIS	ANNUAL/BIANNUAL ASSET UPDATES	ACCURACTE GIS PARCEL LAYER	IDENTIFYING PHYSICAL ENCROACHMENTS	BEST PRACTICES FOR DATA MANAGEMENT	IDENTIFICATION OF PROTECTED VEGETATION AND WILDLIFE SPECIES	STANDARDS FOR DATA COLLECION	RIGHT-OF-WAY/PROPERTY ENCROACHMENTS	EROSION DETECTION	LOCATING HOMELESS ENCAMPMENTS	TEMPORAL DATA STORAGE TO IDENTIFY CHANGES OVER TIME	ACCURACTE GIS PARCEL LAYER	CORRECTIVE MAINTENANCE ISSUES
GE	X							X			X	X														
Harris	X							X			X	X														
Network Mapping	X							X			X															
PwC	X							X			X	X														

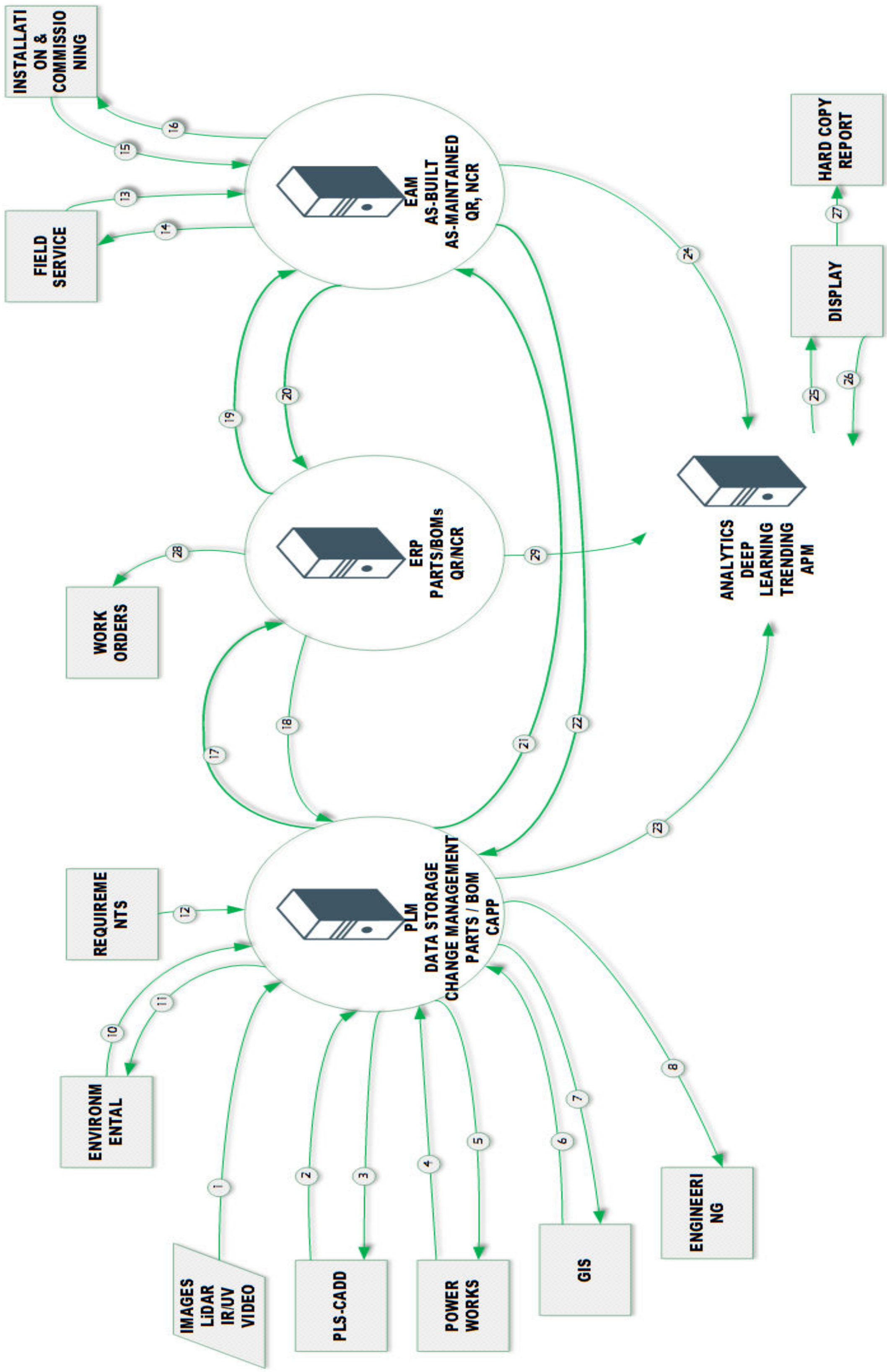
TEST CASE ARE BLUE

COMMON TEST/USE CASE BETWEEN STAKEHOLDERS

7.3 Appendix C: Proposed DMP

7.3.1 Proposed DMP Architecture Diagram

This architecture diagram depicts one proposed DMP structure that would provide storage and access to stakeholder platform and data requirements.


INSTALLATION & COMMISSIONING
FIELD SERVICE
EAM
AS-BUILT
AS-MAINTAINED
QR, NCR
HARD COPY REPORT
DISPLAY
WORK ORDERS
ERP
PARTS/BOMs
QR/NCR
ANALYTICS
DEEP LEARNING
TRENDING
APM
REQUIREMENTS
PLM
DATA STORAGE
CHANGE MANAGEMENT
PARTS / BOM
CAPP
ENVIRONMENTAL
IMAGES
LiDAR
IR/UV
VIDEO
PLS-CADD
POWER WORKS
GIS
ENGINEERING
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7.3.2 Proposed DMP Architecture Diagram Reference Chart

This table identifies the potential data types, format criteria, sources and targets for many of the data sets collected by the ASD group for various stakeholders.

Data Flow Reference Number	Data Type(s)	Data Criteria	Source	Target
1	RGB, LiDAR, IR, UV, Video	RGB - 20Mp, LiDAR +/- 50 mm, IR, UV, Video HD mp4	UAV, Field Service	PLM
2	SHP, LAS		PLS-CADD Session	PLM
3	SHP, LAS		PLM	PLS-CADD Session
4				PLM
5				Power Works Session
6	GPS		GIS Session	PLM, EAM
7	GPS		PLM, EAM	GIS Session
8	Word, Excel, PPT, TXT	.docx, .pptx, .xlsx, pdf	Engineering Session	PLM
9	TXT	ASCII	PLM	Session
10	TXT	ASCII		PLM
11	TXT	ASCII	PLM	Session
12	TXT, XLS, CSV	ASCII	Requirements Mgt. Tool	PLM
13	TXT, RGB, Video, LiDAR	RGB - 20Mp, LiDAR +/- 50 mm, IR, UV, Video HD mp4, ASCII	Session	EAM
14	TXT, RGB	RGB - 20Mp	EAM	Session
15	RGB, LiDAR, IR, UV, Video	RGB - 20Mp, LiDAR +/- 50 mm, IR, UV, Video HD mp4	Session	EAM
16	RGB, LiDAR, IR, UV, Video	RGB - 20Mp, LiDAR +/- 50 mm, IR, UV, Video HD mp4	EAM	Session
17	CR, BOM, CAPP		PLM	ERP
18	BOM, QR		ERP	PLM
19	BOM, Prod. Order		ERP	EAM
20	BOM, SN, QR, PS		EAM	ERP
21	BOM, CAPP		PLM	EAM
22	SN, BOM, NCR, QR		EAM	PLM
23	GIS, SHP, TXT, PW,*		PLM	APM System
24	BOM, RGB, PS		EAM	APM System
25	<<ALL>>		APM System	Display
26	SQL, TXT	ASCII	Input	APM System
27	<<Result>>		Display	Printer
28	BOM, CAPP, Date		ERP	Printer