Energy Research and Development Division

FINAL PROJECT REPORT

High-Accuracy Mapping for Excavation Damage Prevention and Emergency Response

California Energy Commission

Gavin Newsom, Governor

July 2019 | CEC-500-2019-051

PREPARED BY:

Primary Authors:
Robert Marros, Gas Technology Institute
Emily McKenzie, LocusView Solutions
Stephen Meredith, LocusView Solutions
Hamid Abbasi, Gas Technology Institute

Gas Technology Institute
1700 S Mount Prospect Road
Des Plaines, IL 60018
Phone: 847-768-0500 | Fax: 847-768-0501
http://www.gastechnology.org

Contract Number: PIR-15-014

PREPARED FOR:
California Energy Commission

Yahui Yang, Ph.D.
Project Manager

Fernando Piña
Office Manager
ENERGY SYSTEMS RESEARCH OFFICE

Laurie ten Hope
Deputy Director
ENERGY RESEARCH AND DEVELOPMENT DIVISION

Drew Bohan
Executive Director

ACKNOWLEDGEMENTS

The authors would like to acknowledge the support of Pacific Gas and Electric Company for guidance and engineering and technical support through the project technical advisory committee.

PREFACE

The California Energy Commission's Energy Research and Development Division manages the Natural Gas Research and Development program, which supports energy-related research, development, and demonstration (RD&D) not adequately provided by competitive and regulated markets. These natural gas research investments spur innovation in energy efficiency, renewable energy and advanced clean generation, energy-related environmental protection, energy transmission and distribution and transportation.

The Energy Research and Development Division conducts this public interest natural gas-related energy research by partnering with RD&D entities, including individuals, businesses, utilities and public and private research institutions. This program promotes greater natural gas reliability, lower costs and increases safety for Californians and is focused in these areas:

- Buildings End-Use Energy Efficiency
- Industrial, Agriculture and Water Efficiency
- Renewable Energy and Advanced Generation
- Natural Gas Infrastructure Safety and Integrity
- Energy-Related Environmental Research
- Natural Gas-Related Transportation

High-Accuracy Mapping for Excavation Damage Prevention and Emergency Response is the final report for the High-Accuracy Mapping for Excavation Damage Prevention and Emergency Response project PIR-15-014 conducted by Gas Technology Institute and LocusView Solutions. The information from this project contributes to the Energy Research and Development Division's Natural Gas Research and Development program.

For more information about the Energy Research and Development Division, please visit the Energy Commission's website at www.energy.ca.gov/research/ or contact the Energy Commission at 916-327-1551.

ABSTRACT

Accurate and current records of the location of underground natural gas assets are necessary for safe and reliable operation of the natural gas transportation and delivery system. They also help reduce the risk of pipeline damage from excavation. The natural gas system is aging and extremely complex, making it difficult for utilities to know exactly where the assets are located. Mapping is done manually with paper-based methods, which can be time consuming and subject to human error. The high-accuracy mapping system developed and demonstrated in this project uses digitally captured data to create and display high-accuracy maps of the locations and characteristics of natural gas assets to assist utilities and pipeline operators with routine operations and emergency response. The technology used recent advances in mobile, geographic information system, and global positioning system technologies.

The research team configured and demonstrated 22 mapping units in 10 service locations throughout Pacific Gas and Electric Company's service territory. The team used the technology to map 37,951 feet of pipeline and 3,475-point features (such as valves and fittings), and achieved an average location accuracy of less than 6 inches for 91.46 percent of the mapped assets. The mapping data were also incorporated into a Web-based situational awareness tool to provide real-time information on underground natural gas distribution assets and excavation.

This final report describes the results of the project, current and planned technology transfer, and the benefits of the technology to California, and provides recommendations for future actions to improve and increase use of the technology.

Keywords: High-accuracy mapping, excavation damage, safety, monitoring, gas pipelines, risk management, user-acceptance testing.

Please use the following citation for this report:

Marros, Robert (Gas Technology Institute), Emily McKenzie and Stephen Meredith (LocusView Solutions) and Hamid Abbasi (Gas Technology Institute). 2019. *High-Accuracy Mapping for Excavation Damage Prevention and Emergency Response*. California Energy Commission. Publication Number: CEC-500-2019-051.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

EXECUTIVE SUMMARY

Background

Natural gas is a vital source of energy in California, meeting nearly one-third of total energy demand. Maintaining the safety and reliability of the natural gas system is therefore critical. Reducing the risk of negative impacts on the natural gas system is also consistent with California's energy policies to ensure reliable, secure, and diverse energy supplies; enhance the state's economy; protect public health and safety; and reduce the impacts of climate change on the environment.

Much of the natural gas distribution and delivery infrastructure in California and throughout the United States is reaching the end of the design life. To maintain safety and reliability, many states are implementing infrastructure upgrade and replacement programs. These programs provide a unique window of opportunity to create current and accurate high-quality maps and records of the natural gas system as portions of the system are upgraded and replaced.

Because of the age and complexity of the natural gas system, it can be difficult for utilities to know exactly where their assets are in the ground. In addition, maps of natural gas assets are typically created using manual, paper-based methods that can lead to human errors and delays in accessing and making information available to field crews and emergency responders. Inaccurate or incomplete information on the location of natural gas assets can also increase the risk of pipeline damage from excavation, one of the most common causes of pipeline failure. Hazards from damage to the natural gas pipeline system include leaks that can lead to fires, explosions, property damage, physical injuries, and in some cases fatalities. Leaks can also contribute to climate change because the primary component of natural gas is methane, a greenhouse gas 84 times more potent than carbon dioxide. Other impacts include interruptions in natural gas deliveries to homes and businesses and the costs associated with pipeline repairs.

Having current and accurate records of the location of natural gas assets can help ensure safe and reliable operation of the natural gas transportation and delivery system. It can also give pipeline operators the information they need to respond appropriately to emergencies, and provide essential data to "call before you dig" services that identify the locations of underground facilities prior to excavations to prevent damage.

Federal regulations for managing pipeline integrity also provide an incentive for pipeline operators to implement technologies like high-accuracy mapping that can improve and increase data collection, with a specific focus on tracking and traceability data for underground plastic pipelines and fittings. This trend is expected to continue as federal and state governments enact new natural gas pipeline regulations in the future.

Project Purpose

To address the current challenges with locating and mapping natural gas assets, the goal of the high-accuracy mapping project was to develop and demonstrate a mapping system with a relatively large group of users. The system would allow users to use digitally captured data to automatically create and display accurate maps of the locations and characteristics of natural gas pipes, fittings, and other underground assets. The system also allows access to data in near-real time and gives users access to maps that provide information based on users' specific locations and permission levels to various data layers. These maps and records will help utilities and pipeline operators with routine operations, emergency response, and efforts to identify, evaluate, and reduce risks that affect system safety and reliability.

The project builds on a 2015 proof-of-concept effort in which the Gas Technology Institute developed and tested a high-accuracy mapping technology in Pacific Gas and Electric Company's service territory. That effort proved the feasibility of the technology, with follow-up recommendations to test the technology with a larger group of users and demonstrate a system to present maps to those users for visualization and situational awareness.

The high-accuracy mapping project addressed those recommendations and included the following specific objectives:

- Place 20 high-accuracy mapping systems in the Pacific Gas and Electric Company's service territory; encourage adoption of the technology by developing workflows to support the utility's business processes and by identifying barriers to full implementation.
- Develop and use a situational awareness tool to present assets maps to 20 field crews based on their location and the data they have permission to access. Situational awareness can be simply defined as being aware of surroundings such as underground assets, hospitals, fire stations, schools, and emergency vehicles.

Project Approach

High-Accuracy Mapping System

LocusView Solutions, the Gas Technology Institute, and Pacific Gas and Electric Company teams worked closely to develop the high-accuracy mapping system, which was then tested by utility crews in the field. The research team used a prototype mapping system developed by LocusView Solutions that uses mobile applications on iOS (Apple's operating system for mobile devices), Android, and Environmental Systems Resources Institute platforms. The mobile applications connected tablet computers to high-accuracy global positioning system receivers to provide accurate real-time data that could be transferred wirelessly to a cloud-hosted repository to allow users in the utility offices to view data as they were collected.

User acceptance testing was conducted in two phases conducted in spring 2017 at Pacific Gas and Electric Company's offices, the first for use on an Android device, and the second on an iOS system. LocusView Solutions conducted onsite training for utility testers and provided remote support for the duration of the testing. The measurements for project success were (1) the amount of time needed to move field data to the office for review, (2) completeness and accuracy of the mapping data, and (3) user satisfaction.

For both phases, testers were asked to mark “pass” or “fail” on a detailed matrix listing each step in the workflow process and provide notes as needed. Testers also received a list of questions to generate qualitative feedback on individual components of the process. LocusView Solutions reviewed each comment and responded with anticipated dates to resolve the issues, followed by regular updates on issue resolution during weekly status calls.

Once testing was completed, the research team configured and tested 22 mapping units with construction crews at 10 service locations in Pacific Gas and Electric Company’s service territory. Demonstration was carried out in phases, with the 10 locations divided into groups of field crews for training and testing. Eight demonstrations, the first in April 2017 and the last in September 2017, were staggered throughout the project. Data collection began in April 2017 and concluded in March 2018. Construction crews received classroom and outdoor training, followed by job shadowing. During the project, LocusView Solutions provided a field support technician to assist the crews and held weekly status calls to address ongoing issues.

Finally, the project team worked with Pacific Gas and Electric Company to move the high-accuracy mapping technology into production by incorporating a new software application based on the demonstration results, including additional quality control and ease-of-use features. Technology enhancements to prepare for production deployment consisted of:

- Modifying the user interface to clearly display the GPS accuracy using color-coding and prominently displayed accuracy metrics.
- Developing a method to connect to multiple Bluetooth devices without causing interference and disconnections.
- Developing a method to automatically reconnect to real-time kinematic correction service.
- Supporting work to prepare for production deployment consisted of:
    - Creating exports to send to Pacific Gas and Electric Company geographical information system of record (this will facilitate application to other utilities).
    - Establishing help desk and mobile device management for technical support.
    - Establishing real-time kinematic network monitoring system.

Situational Awareness Tool

In addition to demonstration of the high-accuracy mapping tool, the project incorporated mapping data into a Web-based situational awareness tool to provide real-time information on underground distribution assets and excavation activity. Gas Technology Institute worked with Pacific Gas and Electric Company to develop a user case, functionality requirements, and a demonstration and testing plan and then developed the situational awareness Web application. The Web application combined data from multiple sources based on a geographic information system, including freely available data on hospitals, schools, and police and fire resources. Additional information included real-time high-accuracy mapping data and excavation location data to provide important context for ongoing response to an emergency.

After the tool was developed, Gas Technology Institute provided training tools to field workers. Pacific Gas and Electric Company staff then tested the functionality of the application, including (1) ability of the application to display data on the screen at all times, (2) ability of the user to log in successfully every time, and (3) consistent availability of data sources. Issues identified during testing were resolved to the extent possible, since some issues were the result of platform limitations. As in the high-accuracy mapping project, users were asked to complete a checklist with "pass" or "fail" and provide comments as appropriate.

Project Results

High-Accuracy Mapping Project

The research team mapped natural gas assets including 37,951 feet of pipeline and 3,475 point features (for example, valves and fittings). The team was able to accurately map the assets digitally to within less than 6 inches of the actual locations, on average, for 91.46 percent of those assets, with measurements in some cases within one-half inch. This accuracy was consistent with the project target of achieving accuracy within less than 6 inches for at least 90 percent of the collected assets. In general, natural gas assets located away from houses and other buildings could be mapped with greater accuracy. The features mapped with the least accuracy were risers (piping components that connect the underground distribution service line to the above-ground natural gas meter) due to the proximity to buildings and overhangs. Measurement accuracy improved over time because of hardware and software modifications, suggesting there is potential for accuracy improvements.

During the data acquisition phase, users noted that collecting data electronically improved data accuracy and took only minutes to complete compared to the typical manual, paper-based approach that could take one or more hours.

Situational Awareness Tool

Pacific Gas and Electric Company staff feedback from testing of the situational awareness tool indicated the application has potential but requires usability improvements, compatibility with the utility's business processes, and buy-in from field users before it can be demonstrated in the field. Based on testing results, Gas Technology Institute made changes to the application to make the tool easier to access and navigate and to improve the quality of the information display.

The tool was tested but not demonstrated in the field because it was discovered that, under Pacific Gas and Electric Company's emergency response process, the field crews who were the intended users are not expected to make decisions and therefore would not benefit from the situational awareness application.

Gas Technology Institute also conducted a brief survey of 30 gas utilities for feedback on the situational awareness tool. Twelve of the 16 respondents to the gas utility survey indicated they would be interested in a solution that provided capabilities like those in the situational awareness tool developed in the project. However, the solution would need to be highly customized for the gas utility's business process and integrated into its own geographic information system software system.

Technology Transfer

LocusView Solutions, with support from the Gas Technology Institute, will commercialize the high-accuracy mapping technology. The situational awareness tool requires further development and user testing.

Target markets for the technology include natural gas distribution and transmission infrastructure operators, other critical infrastructure operators in the United States and Canada, and companies that provide mapping services to natural gas system operators. The research team estimates the total addressable market for the natural gas distribution industry in the United States is 6,000 field crews, based on a market study that provided an estimated ratio of 0.0015 users per mile of pipe and extrapolated for four million miles of pipeline.

Trends affecting market demand include current and potential future Department of Transportation regulations for natural gas integrity management, the availability of technologies such as tablet computers and mobile geographic information systems, and standards for hardware interfaces, communication protocols, and mapping systems that allow interchange of flexible and modular systems to create systems specific to the utility industry.

The research team believes the potential for market share is high. LocusView Solutions has performed pilot testing with 10 pipeline operators, and expects half of the largest natural gas distribution companies in the United States with more than a million meters to conduct pilot projects of this technology by the end of 2019.

Specific technology transfer activities conducted to date include:

- Activities with Pacific Gas and Electric Company to assist in transitioning the technology to a production environment such as:
    - Conducted information webinars and Web demonstrations for utility executives and staff.
    - Developed a plan, schedule, and budget for full production.
    - Provided updated equipment and training and conducted a stakeholder workshop.
    - Reviewed the condition of existing equipment, replaced damaged parts, and provided additional inventory to allow replacement throughout the transition.
    - Delivered a new software application with user-requested modifications based on the pilot project results, including additional quality control and ease-of-use features.
    - Developed a workflow for integrating data into the enterprise geographic information system and criteria for removing paper forms and records.
    - Provided training and technical support to users.

    - Discussed a plan to transition the technology to a live full-time production environment.
    - Delivered a preproduction application with new features and updates requested by the utility after the pilot project.
- Presentations at industry events including the American Gas Association's Annual Operations Conference, the ESRI GeoConX Conference, and the Western Energy Institute's Operations Conference.
- Advertisements in trade journals including *American Gas Magazine* and the *Pipeline and Gas Journal*.
- Conversations with nearly 50 American Gas Association member utilities about the high-accuracy mapping technology during their tour of the Gas Technology Institute facilities in April 2018.

Future project team efforts to market and sell this technology will include:

- Demonstrations and presentations at industry events including the American Gas Association's Annual Operations Conference and the Western Energy Institute's Operations Conference.
- Exhibitions at industry conferences including national and state trade association shows.
- Advertisements in trade journals including *American Gas, Pipeline Gas and Journal*, and the American Public Gas Association's publication, *The Source*.
- Information webinars and Web demonstrations.
- Quantified risk reduction estimates to support business case development for utilities.
- Partnerships with information technology consulting firms to provide a holistic solution that integrates with other information technology systems.
- Partnerships with field services companies that can provide high-accuracy mapping as a service

Benefits to California

Pacific Gas and Electric Company assumes that full implementation of the high-accuracy mapping technology will help reduce excavation damages resulting from inaccurate location of underground assets in the utility's service territory by more than 50 percent. If fully implemented, the technology could eliminate 300 excavation damage events each year in California, which would reduce natural gas releases from those events by 11,700 thousand standard cubic feet and reduce excavation damage costs by $1.5 million. There would be additional energy savings from a reduction in equipment to transport personnel and repair equipment to damage sites as well as from reduced use of the repair equipment itself. Reducing incidents of excavation damage and the amount of time required to locate assets for engineering, operations, and "call before you dig" activities will also reduce overall utility operating costs.

Reducing natural gas leaks will contribute to California's climate change goals since methane, a primary constituent of natural gas, is a greenhouse gas 84 times more potent than carbon dioxide.

The high-accuracy mapping technology can improve the accuracy and quality of traceability and geographic data collected in the field. Compared to currently available technologies, the technology decreases the amount of time needed to get field data into the mapping database, improves the accuracy and completeness of collected data, and allows data to be collected by construction crews during routine operations. The technology will assist utilities in more effectively locating specific assets that must be repaired or replaced.

Recommendations

A recommendation for technology developers and utilities to improve the high-accuracy mapping system is to identify opportunities to remove paper forms and records from the data collection process in the field.

Recommendations for gas utilities to promote implementation of the high-accuracy mapping system include:

- Purchasing new natural gas assets that have American Society for Testing and Materials traceability bar codes.
- Building business processes that include integration of field collected data into the geographic information system software.
- Implementing a formal change management program: Implementing high-accuracy global positioning systems for mapping will affect various segments on an organization, including geographical information systems, information technology, engineering, construction, integrity management, one-call locating, and emergency response.

Recommendations for technology developers to improve the functionality of the situational awareness tool include:

- Developing a native application (which uses the software development kit provided by the operating system manufacturer) to improve user experience and provide direct access to features in the operating system if needed.
- Minimizing login steps.
- Allowing users to login using their own local area network identification numbers.
- Allowing users to access an offline version of the tool when there is no cellular coverage.

Areas identified by the research team for future research needed in these areas include:

- Eliminating the need for manual records of underground assets.
- Improving the accuracy of underground asset mapping.
- Improving the consistency of mapping accuracy between users and equipment.

- Developing a tool to provide real-time predictive information based on historical incidents.
- Funding the development of technologies that leverage high-accuracy maps.

CHAPTER 1: Project Purpose and Approach

Background

Natural gas meets nearly one-third of California's energy demand for heating, cooking, electricity generation, and alternative transportation fuels. As a result, maintaining the safety and reliability of the state's natural gas system is of critical importance.

The natural gas infrastructure that provides gas to customers includes production of raw natural gas from underground formations, removal of impurities and other substances to ensure that the gas meets specific pipeline-grade requirements, and delivery of the gas to residential, commercial, and industrial users. A large portion of the natural gas distribution and delivery infrastructure in the United States is reaching the end of its design life. Many states are therefore aggressively putting infrastructure upgrade and replacement programs in place to maintain the safety and reliability of the system. These programs represent an opportunity to create high quality asset maps and records of the natural gas system using accurate and current data that can be used in future programs to manage natural gas assets and integrity, as well as for routine operations and emergency response.

A key challenge for natural gas utilities is knowing where their assets are in the ground. Natural gas operators typically use manual, paper-based methods to create asset maps, but these methods can lead to human errors as well as delays in making asset and engineering information available to field crews, one-call locators,[1] and emergency responders. Accurate, current records are essential for pipeline operators to have the situational awareness needed to deal with emergencies. Accurate records are also critical to allow utilities to locate and mark underground facilities before excavations to prevent damage to the system, interruptions in natural gas service and, in some cases, property damage or personal injury.

To help provide more current and accurate maps, Gas Technology Institute (GTI), with funding from Operations Technology Development, Not for Profit[2] (OTD NFP), developed a HAM technology that was tested in 2015 in a limited test with Pacific Gas and Electric Company (PG&E). This earlier proof-of-concept effort with PG&E proved the technical feasibility of the technology, with two PG&E end-users mapping 111 natural gas system features (for example,

---

[1] "Call before you dig" services. For example, 811 is a service managed by Underground Service Alert that will alert utilities and other companies with underground lines in your area so that representatives can mark the location of their underground lines so that they can be avoided. See http://www.california811.org/.

[2] OTD is a member-controlled partnership of natural gas distribution companies formed to develop, test, and implement new technologies relating to gas operations and infrastructure. https://www.otd-co.org/Pages/default.aspx.

valves and fittings) and 1,373 feet of pipe accurately to within an average of 7.65-inches of their actual values, with 90 percent of the features mapped having an accuracy better than 6 inches.

Recommendations for next steps after the proof-of-concept included demonstration and testing with a larger group of end-users to present asset maps to end-users for visualization and situational awareness, both of which were addressed in the project that is the subject of this report. Additional recommendations included developing a solution to capture additional information during the installation process to eliminate the use of paper maps and records and developing a process to seamlessly integrate with the enterprise software system. These recommendations and anticipated to be addressed in future work funded by utilities or others.

Project Purpose

The high-level goal of the HAM technology project was to demonstrate and test a system that can automatically create and display high-accuracy maps of natural gas system infrastructure that include tracking and asset traceability—for example, barcode or global positioning system (GPS) location information—showing the locations of pipes, fittings, and other underground assets. A secondary goal was to provide a situational awareness tool to present the asset maps to field crews.

To achieve these goals, project objectives were:

- Demonstrate 20 HAM systems in the PG&E service territory and support adoption of the systems into the utility's enterprise software by (a) developing workflows that support PG&E's business processes, and (b) identifying barriers to full deployment of the technology. The measurement for successful performance was the time required to get map data from the field into the enterprise GIS.
- Demonstrate the situational awareness tool to present asset maps to 20 field crews based on their location and what data they are permitted to access. The performance metric was the accuracy and completeness of the map data presented to each user.

Technical Approach

Table 1 shows the tasks that addressed the project objectives.

Table 1: Technical Tasks

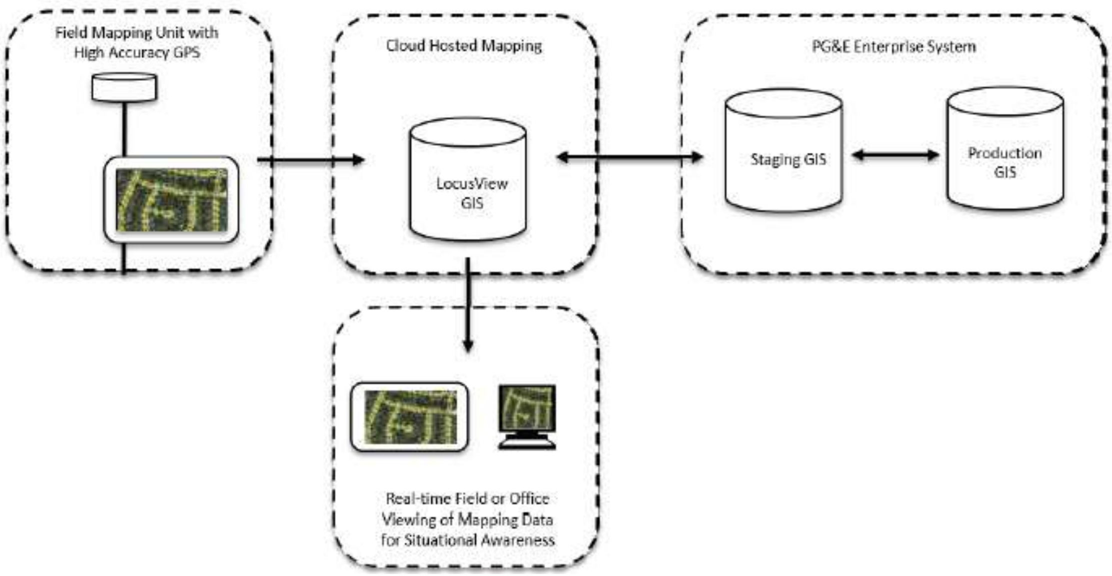
Task Name	Goal
HAM Configuration	Configure 20 HAM units for demonstration and testing at PG&E
HAM Pilot Project	Demonstrate and test 20 HAM units to PG&E end-users for a 6-month pilot project.
Situational Awareness Tool Configuration	Configure the situational awareness tool for demonstration and testing with 20 users at PG&E.
Situational Awareness Tool Pilot Project	Demonstrate the situational awareness tool to 20 PG&E end-users in a 60-day pilot project

Source: GTI

Figure 1 shows a high-level architecture of the HAM system. Researchers performed field mapping using LocusMap (mapping software developed by LocusView Solutions [LVS]) with high-accuracy GPS devices connected via Bluetooth to iOS (Apple's Operating System for Mobile Devices) tablets. Barcode scanners were used to read American Society for Testing and Materials barcodes when available, and the barcode scanner was also connected via Bluetooth to the iOS device. Data collected in LocusMap was synchronized in near real time to LVS's cloud-hosted database. This allowed users in the office to view the data as it was collected in the field. The data was not integrated into the PG&E Enterprise System during the project. Prior to field demonstration, two phases of user acceptance testing were carried out with PG&E staff to identify and address any issues and improve system performance.

Chapter 2 provides a detailed discussion of the development and testing of the high-accuracy mapping technology.

Figure 1: System Architecture



Source: LocusView Solutions

To develop the situational awareness tool, GTI worked with PG&E to define a use case, functionality requirements, and a demonstration and testing plan. Using information gathered from PG&E, GTI subsequently established a set of application requirements that served as the basis for developing the tool. The Environmental Systems Resources Institute (Esri) Web AppBuilder (developer edition) was used as the platform to develop the application. This platform provided a single solution that worked for both mobile devices and Web-based applications. Once the application was configured, it was hosted on GTI's Amazon Web Services environment to provide the most efficient access and security for the application. Chapter 3 provides more detail on development and testing of the situational awareness tool.

CHAPTER 2: High-Accuracy Mapping Technology

The high-accuracy mapping (HAM) technology creates spatially accurate maps of the natural gas system that includes traceability data for materials, joints, operator qualifications status, and pressure tests. Key features are mobile geographic information system (GIS) applications, high-accuracy global positioning system (GPS), barcode scanning, and sensor-based data collection.

The technology provides material traceability that reads and decodes American Society for Testing and Materials (ASTM) F2987 or other barcodes, creates GIS features, populates attribute information, and maps assets with high-accuracy GPS. The technology also provides tracking for joints (welds, fusions, or mechanical fittings) which captures make, model, calibration, and fusion data from the pipe joining fusion machine. It also creates joint and traceability barcodes.

Overview

The HAM software application captures high-accuracy GPS and material traceability data and automates the creation of GIS maps and related records. The software uses mobile applications to capture data and synchronizes data to a cloud-hosted database.

Figure 2 shows the specific hardware used to capture, and record mapping data. The HAM hardware used in the pilot project included tablets (iPad Mini), GPS receivers, GPS antennas, barcode scanners and 7-foot survey poles.[3] The GPS receivers and barcode scanners were paired to the iPad Mini to synchronize data with the mobile application. In each HAM system, the tablet, GPS receiver, and GPS antenna were mounted to the survey pole, while the barcode scanner was handheld. The GPS receiver and barcode scanner were connected to the tablet using Bluetooth, while the GPS antenna was hard-wired to the GPS receiver.

For mapping, the survey pole equipped with the tablet, the GPS unit, and the antenna is aligned with the pipe or fitting to be mapped and its location is measured and recorded.

The system reads ASTM F2897 material traceability barcodes that contain asset information such as asset type, size, material, manufacturer, production date, and lot number. The software automatically creates GIS features based on the asset type and automatically populates the feature's attribute information based on the ASTM F2897 barcode.

The HAM system also creates joint traceability barcodes and captures joint information including the pipe joining fusion machine make, model, calibration date, and the operator qualifications of the person performing the joint. The application can integrate directly with specific electrofusion machines on site during the fusion process to extract fusion records and parameter data.

[3] A survey pole is a bar made of wood or metal, normally held vertically, on which instruments can be mounted.

Figure 2: High-Accuracy Mapping Hardware

Source: LocusView Solutions

Configuration

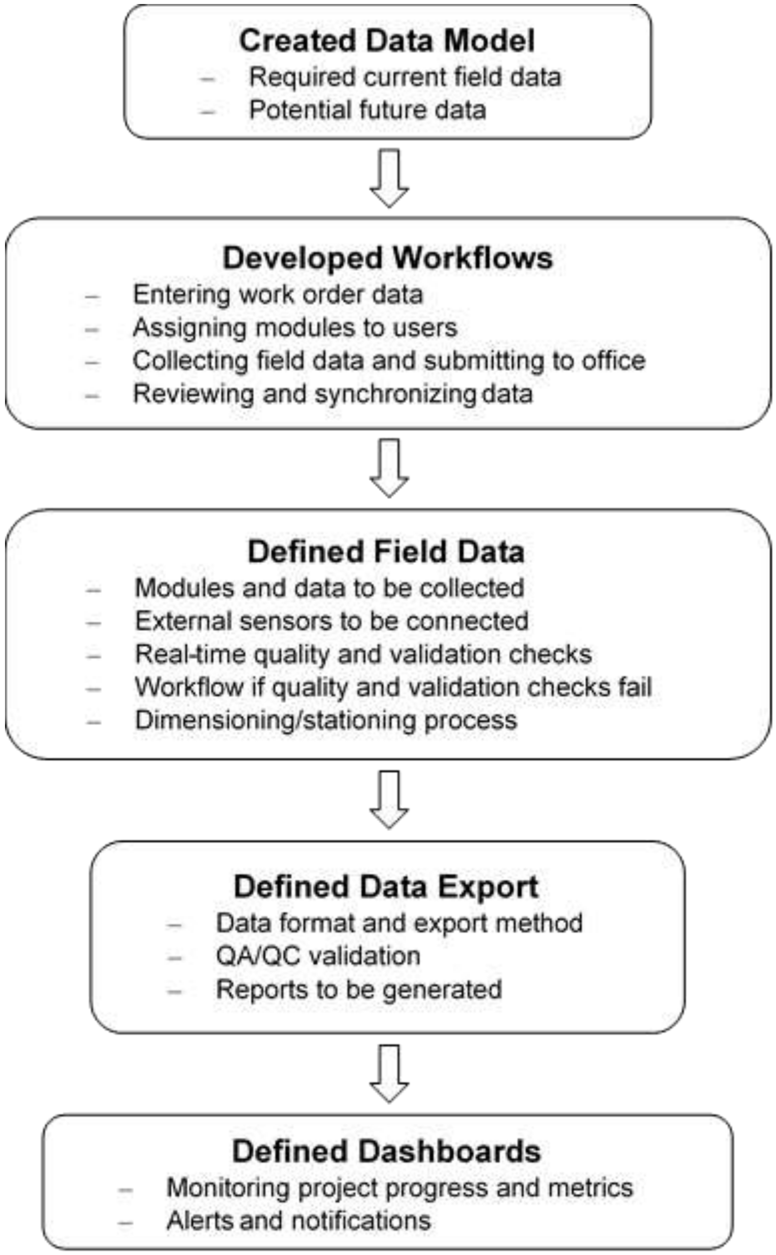
The LVS, GTI and PG&E teams worked closely to develop a tracking and traceability solution to meet PG&E's needs, a robust cloud-based software combined with iOS, GPS and barcode scanning hardware that would satisfy PG&E's data collection requirements. The team then developed and configured the mobile application for collecting, processing, and displaying data on GPS location and asset attributes provided through barcode scanning and manual entry. Field mapping was performed using high-accuracy GPS devices connected via Bluetooth to iOS tablets. Barcode scanners were used to read ASTM barcodes when available, connected via Bluetooth to the iOS device. Data collected using the LocusMap mapping software was synchronized near real time to the LVS's cloud-hosted database.

Software Design

The HAM software application was designed by identifying the requirements based on discussions between team members and PG&E staff, defining the data model, defining the workflow, conducing an on-site demonstration, developing a wireframe (a visual guide that represents the framework of a website), and delivering a design document for approval. Figure 3 shows the sequence of key steps.

The design document defined the scope of the system to be delivered, including hardware, software, data model, and required functionality. The team then developed and configured the mobile application, the dashboard, the cloud environment, and data import/export methods.

Figure 3: Software Design Steps



Source: LocusView Solutions

Hardware Configuration

The hardware was selected, modified and built based on the specifications outlined in the design document. PG&E had options for tablet specifications, pole attachments, chargers, and so on. Hardware included:

- Tablet: iPAD mini: Selected by PG&E using its company-wide equipment standard. The iPAD Mini was selected over a cellphone due to its larger screen size and readability.
- Barcode Scanner: Zebra—selected for performance and scanning capabilities.

- GPS: EOS Arrow Gold Global Navigation Satellite System (GNSS) Receiver: Selected for performance, accuracy and battery life.
- Survey pole.
- Charging cables and accessories.
- Carrying case.

Figure 4 shows the tablet (left), the GPS receiver (middle), the barcode scanner (right) and the attachment hardware in a portable carrying case.

Figure 4: Tablet, Barcode Scanner and Attachment Hardware

Source: LocusView Solutions

Figure 5 shows the system being used to collect mapping data in the field. For mapping, the tablet and the GPS unit are mounted on a survey pole, which is aligned with the pipe or fitting to be mapped. Once the pole is stable and the antenna is level, the unit is able to measure and record the survey data. Any tilt or lean to the pole creates inaccuracies because the antenna at the top defines the GPS coordinates received and recorded, so a level is attached to the pole to aid in its positioning.

Figure 5: Survey Pole with Attached Tablet in Field Use

Source: LocusView Solutions

Figure 6 shows the Real-time Kinematic (RTK) base station that provides real-time correction factors for mobile GPS antennas. The pilot project included multiple RTK base stations in the PG&E service territory, with each RTK base station consisting of the following hardware:

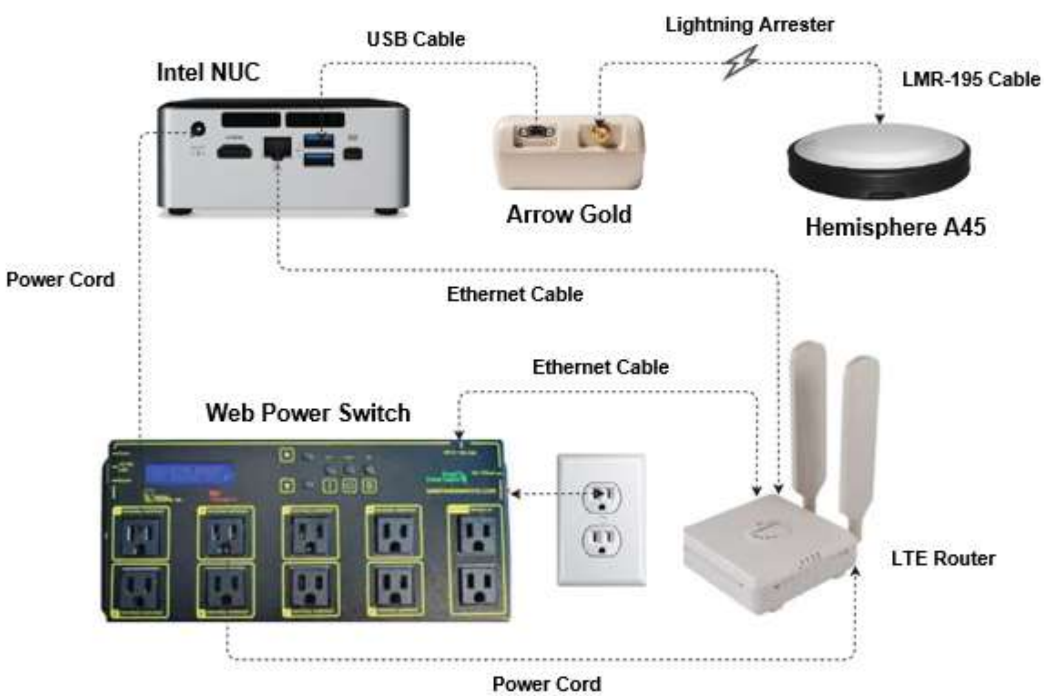
- Receiver: EOS Arrow Gold GNSS receiver
- Antenna: Hemisphere A45 GNSS antenna
- Personal computer: Intel NUC Mini
- Low-loss antennae cable
- Web power switch
- 4G/LTE router
- Lightning protector
- Miscellaneous peripherals

Figure 6: Base Station

Source: LocusView Solutions

Figure 7 shows the architecture diagram for the Base Station System.

Figure 7: Base Station System Architecture



Source: LocusView Solutions

The Hemisphere A45 GNSS antenna and the Arrow Gold receiver collect location information from multiple GPS satellites. This data is processed by the Intel NUC Mini PC and correction factors are transmitted wirelessly via the router to the survey tablet for real-time correction of the collected data. Multiple base stations spread across the demonstration and testing field site were used to further improve accuracy of HAM data.

User Acceptance Testing

The user acceptance testing (UAT) was divided into two phases, both conducted in spring 2017 at PG&E's offices. The first phase tested the application and configuration on an Android device with a standard data model. The second phase tested the application and configuration on an iOS (Apple's Operating System for Mobile Devices) device with PG&E's custom data model. The same UAT plan, including the test scripts and assessment questions, was used for both phases. This section includes a summary of the testing activities and results for each UAT phase.

Testing Components and Process

The HAM software and hardware were tested on-site at PG&E by their R&D and Innovation staff. The testing included the following components:

- Mobile application for mapping with high-accuracy GPS and material traceability.
- Cloud-hosted server.
- GIS Web viewer.
- Dashboard.
- Hardware (tablet, barcode scanner, GPS and accessories).
- User guides.

LVS provided on-site training to PG&E testers followed by remote support for the duration of the UAT through Helpdesk and Mobile Device Management. Testers were instructed to document testing results using a provided checklist and feedback form, and to capture screenshots of errors, bugs, or unexpected performance and provide detailed written feedback, if possible, to be logged in the UAT Report.

Metrics for Success

The overall key metrics for project success were:

- Amount of time required to move mapping data from the field to the office for review.
- Accuracy and completeness of mapping data.
- User satisfaction.

Specific metrics for key elements are listed in Table 2. The goals for these elements were established in collaboration with PG&E at the beginning of the project. "Times used" is the number of jobs in which an end user used the HAM technology. Each project is defined as a segment of work assigned through a work order. The critical metric is the accuracy, which was considered successful if 90 percent of the measurements were within 6 inches of actual values.

Table 2: Key Success Targets

Metric	Goal
Times Used	150
Total # of Projects	150
Total Fittings	1,000
Feet of Pipe	50,000
% <6 Inches Accuracy	90%
% Scanned from Barcode	50%

Source: LocusView Solutions

Phase 1 Testing – Android Mobile Device

Process

The mobile application testing was performed outdoors at PG&E offices to allow for proper GPS testing and simulate field conditions. PG&E's staff performed the actions outlined in the test scripts with the mapping unit (mobile application, GPS receiver, and barcode scanner). After the test scripts were completed, the collected data was reviewed using Web tools (GIS Web viewer and data metric dashboard).

Test Case Results

Table 3 shows the results of Phase 1 testing by PG&E employees using the Android mobile device. PG&E provided the notations for pass/fail and the comments. Of the three workflows, only two individual tasks failed. The first was the ability to capture a photo and attach it to the entire project, and the second was the ability to delete a valve feature. These capabilities were considered necessary for demonstration and testing and were set as priorities for the final UAT.

General Assessments Results

The following questions were provided to PG&E during UAT to generate qualitative feedback on individual components of the solution. PG&E's responses are shown in bold.

Hardware

1. Did the tablet function properly (speed, visibility, etc.)? **Yes**
2. Did the GPS and barcode scanner connect properly? Did they stay connected? **Yes, and Yes**

Mobile Application

1. Did the application successfully scan all ASTM F2897 barcodes? **Yes. The tablet barcode scanner is limited in capabilities; it could not scan the laser etched barcode or a slightly curved QR (Quick Response) code.**

Table 3: Test Scripts and Results – User Acceptance Testing Phase 1

ID	Action	Pass/Fail	Comment
1	Create project number 12345678	Pass	
	Map a service line pipe segment, Excess Flow Valve (EFV), and coupling under existing project number 12345678	Pass	
	Map a main pipe segment and tapping tee under existing project number 12345678	Pass	
	Add a picture to the EFV feature	Pass	
	Add a comment to the service line in project 12345678	Pass	
	Map a valve and add a picture	Pass	
	Map a reducer using manual entry and add a comment	Pass	
	Map a reducer by manually entering the 16-digit ASTM F2897 identifier found on the barcode (to be provided by LVS)	Pass	
	Map a meter set close to a building	Pass	
	Capture a picture that is associated with the entire project	Fail	Capability not in this version
	Close the project	Pass	
2	Create Project Number 87654321	Pass	
	Map a main of approximately 100 ft. in length. Move the location of the last point of the main to a different location using touch screen	Pass	Need the ability to remap any existing point using GPS
	Map a service line with at least four vertices and delete the last two vertices	Pass	
	Close the project	Pass	
	Create project number 987654321	Pass	
3	Map a tapping tee, EFV, and connecting main and service line segments	Pass	
	Map a meter set close to a building	Pass	
	Walk at least 300 ft. away from the tablet with the barcode scanner and then return to the tablet to simulate losing Bluetooth connectivity. Map an electrofusion fitting	Pass	Barcode scanner did not lose connectivity at this distance
	Turn the GPS receiver off to simulate losing power. Map a valve. Turn the GPS receiver on and map the same valve	Pass	
	Map a new valve feature from the material list and enter the lot code 12345678567. Delete this valve feature from the list	Fail	Capability did not exist in this version
	Close the project	Pass	

Source: LocusView Solutions

2. Did the editing and delete buttons work properly? **Yes, but only the last points collected can be deleted (basically an undo function).**
3. Was the aerial imagery at a resolution that was sufficient? **No, could not zoom in close enough to see the difference between each point, when they are place within a few feet of each other.**

Dashboard

1. Does the dashboard have the correct charts and graphs?
   - Pipe tab is not showing data
   - Want to see a breakdown of the GPS data (RTK), float RTK, internal GPS, manually
2. Does the dashboard update in near real-time as data is posted to the server? **Same day yes, did not check real time**
3. Are the charts and graphs accurate? **Yes**
4. Are the charts and graphs easy to read and understand? **Yes**
5. Does the dashboard show the desired metrics? **Yes, and we may ask for additional metrics after we see real data come in**

Web GIS

1. Are all features posted to the GIS Web viewer in near real time? **Yes, same day. Did not check real time**
2. Are all attributes populated correctly? **Yes**
3. Are the correct layers available? **Yes, but provide enhanced ability to differentiate between feature types**
4. Are the correct tools available? **Would like daily export of data during pilot**
5. Are attribute tables correctly displayed? **Add GPS accuracy and GPS latitude/longitude to the attribute table – these should be the first columns after the project/ticket number**
6. Does the Address and Coordinate search functionality work as expected? **Yes**
7. Are photos linked to assets and viewable if applicable? **Yes**

Additional PG&E Comments

PG&E also provided the following additional comments with associated priorities:

First Priority

1 Need the ability to toggle manual placement. PG&E does not want users to be able to manually place points or accidentally move GPS points.

2. The map should default to the user's current location.
3. The base map zoom is a high priority.
4. For the "latest results list" – change title to "Asset List" and categorize by date. Add capability to filter by date, address, asset type (in addition to size).
5. Add a sub project number, for example address (specific to services).
6. Remove the ability to manually type the ASTM code.
7. Change "Remove Work Request" to "Complete Work Request."
8. Confirm when a point is captured manually, this flags on the back end.

Second Priority

9. Need the ability to click on any asset on the map view to see the attributes (for example, is it a main, EFV, etc.).
10. The on screen GPS accuracy should be in inches not feet.
11. Add a title bar of what was scanned to the joint screen.

Third Priority

12. PG&E will determine the workflow for how and when to identify main and service status.
13. PG&E to determine the workflow for the collection of a fusion barcode. For example, do we want to allow users to bypass this during the mapping portion of the workflow?
14. Need to hear the beep when a barcode is successfully scanned, having the barcode scanner vibrate a little will not be sufficient.
15. Allow a picture to be linked to a sub project # (for example, address).
16. The sound of the barcode scanner disconnecting and reconnecting each time an asset is mapped will likely become annoying to the users. Is there any way to mute this?

Plan for Resolution of Issues

Each comment and issue was reviewed and logged into LVS's ticketing and tracking system with associated priorities. PG&E was given access to the ticket management system and the ability to add and track items as needed. LVS assigned planned resolution dates and provided regular updates on the status of resolution during the weekly status calls.

Phase 2 Testing – iOS Mobile Device

Process

The mobile application testing was performed outdoors at PG&E offices to allow for proper GPS testing and simulate field conditions. PG&E's staff performed the actions outlined in the test routines with the HAM system. After the test routines were completed, the collected data was reviewed using the GIS Web viewer and data metric dashboard.

Test Results

Table 4 on the following page shows the results of the test routines using the iOS mobile device. The notations for pass/fail and the comments were provided by PG&E. Of the three workflows, only one individual task failed, which was the ability to capture a photo and attach it to the entire project.

General Assessments Results

The following questions were provided to PG&E during UAT to generate qualitative feedback on individual components of the solution. PG&E's responses are shown in bold below.

Hardware

1. Did the tablet function properly (speed, visibility, etc.)? **Visibility is poor under sunlight.**
2. Did the GPS and barcode scanner connect properly? Did they stay connected? Flipping between RTK Fixed and Float. **Barcode scanner paired promptly each time**

Mobile Application

1. Did the application successfully scan all ASTM F2897 barcodes? **Yes, with the exception of pipe that was barcoded through laser etching which resulted in a light gray barcode instead of the black ink.**
2. Did the editing and delete buttons work properly? **Yes, but would like the ability to view/edit attributes by clicking on the asset point on the mapping screen versus toggling through a list**.
3. Was the aerial imagery at a resolution that was sufficient? **No, still needs to be fixed**

Dashboard

1. Does the dashboard have the correct charts and graphs? **Yes, but may need additional metrics after pilot data is collected.**
2. Does the dashboard update in near real-time as data is posted to the server? **Did not test.**
3. Are the charts and graphs accurate? **Did not test.**
4. Are the charts and graphs easy to read and understand? **Yes**
5. Does the dashboard show the desired metrics? **Yes, but may need additional metrics after pilot data is collected.**

Web GIS

1. Are all features posted to the GIS Web viewer in near real time? **Did not test.**
2. Are all attributes populated correctly? **Need to see GPS coordinates of each line point captured (similar to how we can see the GPS accuracy of each point)**

Table 4: Test Scripts and Results – User Acceptance Testing Phase 2

ID	Action	Pass/Fail	Comment
1	Create project number 12345678	Pass	
	Map a service line pipe segment, EFV, and coupling under existing project number 12345678	Pass	
	Map a main pipe segment and tapping tee under existing project number 12345678	Pass	
	Add a picture to the EFV feature	Pass	
	Add a comment to the service line in project 12345678	Pass	
	Map a valve and add a picture	Pass	
	Map a reducer using manual entry and add a comment	Pass	
	Map a reducer by manually entering the 16-digit ASTM F2897 identifier found on the barcode (to be provided by LVS)	Pass	
	Map a meter set close to a building	Pass	
	Capture a picture that is associated with the entire project	Fail	Feature not part of system design
	Close the project	Pass	
2	Create project number 87654321	Pass	
	Map a main of approximately 100 ft. in length. Move the location of the last point of the main to a different location using touch screen	Pass	Request for warning prior to moving a mapped point
	Map a service line with at least four vertices and delete the last two vertices	Pass	
	Close the project	Pass	
	Create project number 987654321	Pass	
3	Map a tapping tee, EFV, and connecting main and service line segments	Pass	
	Map a meter set close to a building	Pass	Riser not on drop down list
	Walk at least 300 ft. away from the tablet with the barcode scanner and then return to the tablet to simulate losing Bluetooth connectivity. Map an electrofusion fitting	Pass	Bluetooth connectivity was not lost
	Turn the GPS receiver off to simulate losing power. Map a valve. Turn the GPS receiver on and map the same valve	Pass	
	Map a new valve feature from the material list and enter the lot code 12345678567. Delete this valve feature from the list	Pass	Request for better filtering of latest results screen for example, by date/time, user, material, subproject
	Close the project	Pass	

Source: LocusView Solutions

3. Are the correct layers available? **Yes**
4. Are the correct tools available? **Yes**
5. Are attribute tables correctly displayed? **Yes**
6. Does the Address and Coordinate search functionality work as expected? **Yes**
7. Are photos linked to assets and viewable if applicable? **Yes**

User Guides

1. Are the digital versions available on the tablet? **Yes**
2. Does the PG&E specific user guide include all required workflows? **No, comments provided verbally**
3. Are the instructions clear and easy to follow? **Some steps missing, comments provided verbally**
4. Are common troubleshooting items included on the user guides? **Yes**

Additional PG&E Comments

PG&E also provided the following additional comments:

1. Audible warning to indicate poor accuracy did not work.
2. GPS accuracy indicator should be set at 6 inches.
3. Butt fusion workflow is better, but still somewhat confusing.

When comparing the performance of the iOS tablet to that of the Android tablet, we found no meaningful difference between the two. Given PG&E's decision to standardize company-wide on iOS technologies for all mobile platforms, LVS moved forward with providing iOS tablets for the duration of the project since corporate standards tend to dictate the type of operating system to be used.

Pilot Project

After the UAT was complete, LVS configured, tested, and demonstrated 22 HAM units with PG&E construction crews at 10 service locations throughout PG&E's service territory. Demonstration and testing occurred in phases, with the 10 service locations divided into groups of users for training and testing. There were eight demonstrations staggered throughout the project, with the first demonstration beginning in April 2017 and the last occurring in September 2017. Data collection began in April 2017 and concluded in March 2018 to allow for completion of this report. Each crew was given one day of classroom training consisting of application demonstrations, reviewing user manuals, and hands-on use. This was followed by training conducted outdoors at the training facility, where simulated facilities were mapped in a parking lot environment. Afterwards, there were one to three days of job shadowing, which consisted of training in the field at actual job sites to ensure the crews were competent with the use of the hardware and software.

During the pilot project, LVS provided a field support technician to assist with field training, hardware management, troubleshooting, and gathering feedback. LVS also held weekly status calls to review the collected data, receive feedback, and address any on-going issues.

Training Materials

As part of the training, LVS provided digital and print versions of a user manual and field-specific job aids. The user manual consisted of general application functionality and module workflows, while the job aids consisted of abridged versions of instructions on using a particular module appropriately (the final version of a job aid document is included as Appendix A). The digital versions were provided for distribution to the users and the job aids were printed and laminated for durability in the field. Regular updates were made to both documents when new application updates were released to the field users. LVS also provided a series of training videos to give the users a basic understanding of how to use the HAM equipment and application properly. Subsequently, LVS developed an e-Learning platform to be provided to PG&E for production deployment.

The user manual contained:

- Introduction detailing sign-in instructions, definitions, and how to use the application.
- Mapping Module instructions detailing the workflow, how to collect both point (fitting) and line (pipe) features, mapping with or without barcodes, and mapping inside and outside of a trench.
- Troubleshooting guide for Bluetooth, GPS, and barcode scanner.

The job aid contained instructions for:

- Logging into the application
- RTK settings
- General usage workflow
- Barcode reading
- Manual material entry
- Mapping existing assets
- Submitting a project
- Best practices

Data Collection and Analysis

The field trials of the HAM system were conducted by PG&E construction crews and contractors for service and main installations in the PG&E service territory over 10 months. The following sections summarize the field collected data for the official field trial period from May 26, 2017 to March 30, 2018.

Quantitative Results

The 22 users collected data on 3,475 natural gas system features (fittings, valves and pipe segments) including 2,551-point features (fittings and valves) and 37,951 feet of pipe. Figure 8 displays the collected data and the associated legend. Note the line features do not appear at this level of zoom. The following sections further describe the breakdown of the features collected.

Figure 8: Map of Full Extent of Collected Features from May 26, 2017 through March 30, 2018

Source: LocusView Solutions

On average, the users collectively captured an average of 17 features and an average of 190 feet of pipe per day, representing the typical amount of fittings and pipe installed each day by each user. Collecting the data electronically took only minutes compared to paper-based data collection and creating a sketch, which typically took one or more hours to complete. Collecting data electronically also improved the accuracy of data and location information. Table 5 and Table 6 show the total length of pipe and other data collected by the users.

Table 5: Pipe and Fittings Data Collected During Pilot Project

User	Main Distribution Line (ft)	Service Distribution Line (ft)	Total Pipe (ft)	# of Features	Days Used
User 1	221.66	0	221.66	34	4
User 2	2372.59	1092.73	3465.32	846	23
User 3	36.33	27.34	63.67	433	4
User 4	21.98	176.79	198.78	14	2
User 5	0	230.6	230.6	76	5
User 6	50.48	99.53	150.01	24	5
User 7	2635.8	110.95	2746.75	151	3
User 8	105.27	109.45	214.72	71	7
User 9	0	132.18	132.18	688	1
User 10	286.54	1926.41	2212.95	215	6
User 11	0	77.19	77.19	69	6
User 12	379.77	18.17	397.94	48	61
User 13	440.02	1366.53	1806.55	31	14
User 14	1449.1	537.36	1986.46	33	38
User 15	171.04	0	171.04	20	2
User 16	5436.51	1643.93	7080.44	29	17
User 17	28.29	0	28.29	25	2
User 18	453.36	102.28	555.64	85	9
User 19	5.24	131.69	136.93	50	3
User 20	1077.27	913.58	1990.86	185	12
User 21	4810.81	547.94	5358.74	337	6
User 22	6447.4	2277.25	8724.66	11	16
Total	26429.48	11521.9	37951.38	3475	246

Source: LocusView Solutions

Table 6: Items Collected by Feature Type

Feature	Count
3-Way Tee	120
Adapter Coupling	12
Branch Saddle	4
Coupling	965
EFV	420
Elbow	92
End Cap	190
High Volume Tapping Tees	7
Pipe	924
Reducer	24
Riser	246
Service/Valve Tee	9
Service Saddles	1
Tapping Tee	424
Tee	20
Transition Fitting	8
Valve	9
Total	3475

Source: LocusView Solutions

GPS Accuracy

The overall average GPS accuracy was within 7.69 inches of the actual values for the fittings and 5.19 inches for the pipe. Features that were inadvertently mapped with the low-accuracy GPS on the tablet instead of the high-accuracy external GPS were removed from the analysis. More details on the overall GPS accuracy for each feature, project, and user respectively are in Table 7, Table 8, and Table 9. While the features with the least accuracy were risers due to their proximity to buildings and overhangs, the next two least accurate features, adapter couplings and tees, were due primarily to a few poor accuracy outliers with a small amount of total mapped features. The final column in the tables, "% Below 6 inch", represents a PG&E threshold requirement signifying the amount of latitude given to users to map their systems at high accuracy.

Table 7: GPS Accuracy by Point Feature Type

Feature	Average Accuracy (in)	Median Accuracy (in)	% Below 6 inch
3-Way Tee	4.20	1.17	90.24%
Adapter Coupling	24.60	1.56	71.43%
Branch Saddle	1.66	0.98	100.00%
Coupling	6.78	1.23	88.87%
Elbow	8.29	2.29	71.15%
End Cap	2.58	1.14	97.41%
EFV	3.87	1.20	91.01%
High Volume Tapping Tees	1.16	0.73	100.00%
Pipe	5.19	1.36	87.59%
Reducer	4.17	1.06	88.89%
Riser	30.21	3.39	61.76%
Service / Valve Tee	3.59	1.34	70.00%
Tapping Tee	3.27	1.17	92.93%
Tee	16.19	4.85	57.14%
Transition Fitting	5.02	1.45	87.50%
Valve	7.31	0.98	80.00%

Source: LocusView Solutions

As with features having worse average accuracy because of their proximity to obstructions, the same can be found on the more general scale of project type. For service projects close to houses and other buildings, it is more difficult to map assets with high accuracy. In comparison, the main installations are usually away from houses and have a better chance of attaining a fixed position from the GPS unit for improved mapping accuracy.

Table 8: Average and Median Accuracy by Project Type

Type	Average Accuracy (in)	Median Accuracy (in)	% Below 6 inch
Main	5.43	1.22	92.88%
Service	9.96	1.58	77.32%

Source: LocusView Solutions

When assessing accuracy by user, the pilot project showed that many users attained high average and median accuracies. Users with lower average accuracies (for example, User 6 and 13) took a number of points while not fully connected to the RTK base station. RTK is more accurate and enables the highest quality data because the receiver correlates with and uses the codes transmitted by four or more satellites with known locations to establish its position to within a few meters. The collection of data while not connected to RTK base station caused many outliers in these users' data sets, which greatly decreased their average accuracy compared to other users. Additional training and jobsite observations of PG&E employees improved the higher-inaccuracy users' ability to use the technology more effectively, and the accuracy of GPS readings also improved the more the employees used the system.

Table 9: Average GPS Accuracy per User

User	Accuracy (in)			% Below 6 inch
	Average	Median	Lowest	
User 1	1.46	1.03	3.73	100.00%
User 2	7.63	2.4	124.54	73.02%
User 3	0.63	0.5	7.43	98.55%
User 4	9.41	2.77	110.14	77.08%
User 5	13.86	2.18	119.38	70.97%
User 6	58.16	35.81	300.09	30.30%
User 7	0.87	0.56	2.58	100.00%
User 8	9.64	0.96	214.62	87.50%
User 9	1.02	0.78	4.41	100.00%
User 10	4.51	1.45	65.83	76.47%
User 11	10.33	1.12	173.19	90.00%
User 12	3.17	1.56	110.56	93.74%
User 13	46.92	19.51	1121.09	42.70%
User 14	9.4	0.73	268.69	82.74%
User 15	1.69	1.84	3.27	100.00%
User 16	1.04	0.45	26.09	97.46%
User 17	1.33	1.28	1.78	100.00%
User 18	2.66	0.62	36.7	88.16%
User 19	13.31	2.79	188.1	75.00%
User 20	12.09	0.78	497.59	85.43%
User 21	6.02	3.13	55.84	77.46%
User 22	1.44	1.28	23.38	99.27%

Source: LocusView Solutions

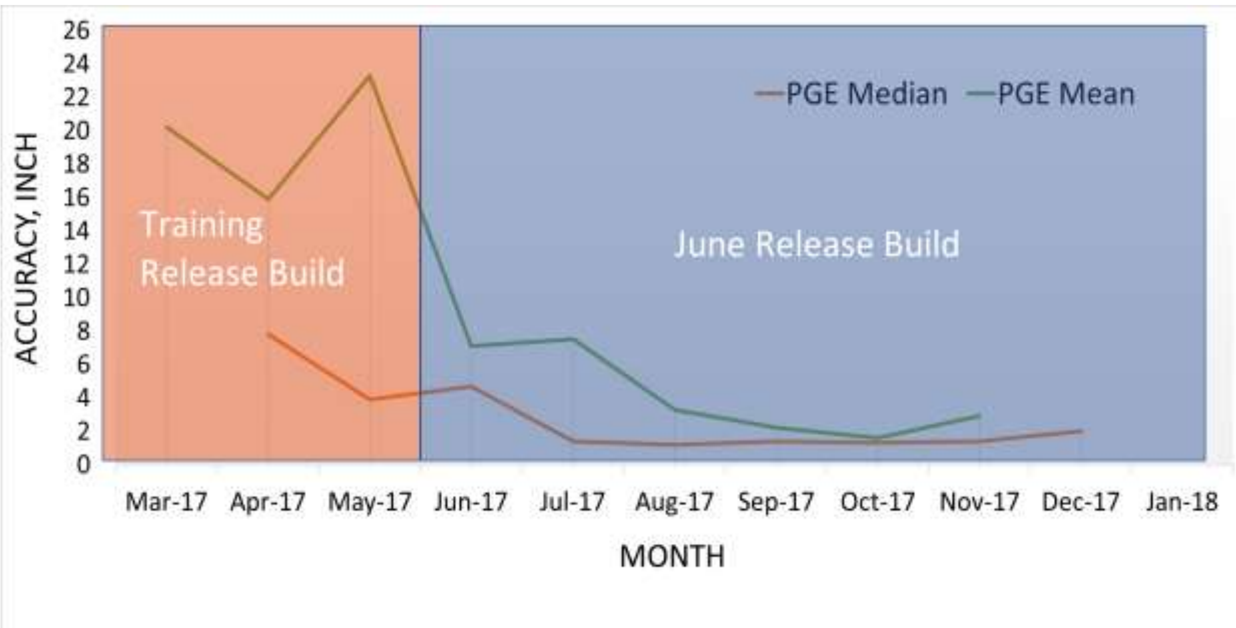
Measurement accuracy improved and stabilized during the first nine months of mapping because of improvements in the RTK base station hardware, RTK logic and user experience (Figure 9).

Barcode Summary

The HAM application provides several methods to collect map data: The options are listed in the preferred order, based on ease of use and accuracy of the data collected.

- Option 1: Scan the ASTM traceability barcode on the asset
- Option 2: Select the asset from a drop-down list (materials list)
- Option 3: Type in the ASTM traceability barcode
- Option 4: Manually enter the data

Figure 9: Median and Mean Accuracy over Time



Source: LocusView Solutions

Overall, 52.72% of the data was captured by barcode scanning, 44.72% collected with the materials list, 1.78% entered manually, and 0.78% entered by typing in the ASTM barcode. The preferred method is to scan the barcode directly from the asset to capture the required traceability information. When entering data through the materials list or manually, the user must also remember to enter the lot code and production date. Such information can be found on the plastic bag the fitting comes in, or the manufacturer's label on the fitting. Table 10 shows the breakdown of these input methods by user and Table 11 shows the breakdown by feature type. There were many reasons for users not being able to use the primary method of entering ASTM information via barcode scanning, including pipes without printed barcodes, obstructions in the trench, and operators installing assets face down so the barcodes were not visible for scanning.

Table 10: Total Number of Features Collected by Input Method per User

User	Barcode	Materials List	Manual	Type ASTM
User 1	5	29	0	0
User 2	153	62	0	0
User 3	33	36	0	0
User 4	18	30	0	0
User 5	21	10	0	0
User 6	25	8	0	0
User 7	3	17	0	0
User 8	6	17	6	0
User 9	3	22	0	0
User 10	26	59	0	0
User 11	5	45	0	0
User 12	651	195	0	0
User 13	93	92	0	0
User 14	95	166	49	27
User 15	3	6	2	0
User 16	164	267	2	0
User 17	2	12	0	0
User 18	8	68	0	0
User 19	17	7	0	0
User 20	34	116	1	0
User 21	28	41	2	0
User 22	439	249	0	0
Total	1832	1554	62	27

Source: LocusView Solutions

Table 11: Percentage of Data Collected by Input Type per Feature Type

Feature	Barcode	Materials List	Manual	Type ASTM
3-Way Tee	64.17%	34.17%	1.67%	0.00%
Adapter Coupling	50.00%	50.00%	0.00%	0.00%
Branch Saddle	0.00%	100.00%	0.00%	0.00%
Coupling	68.81%	29.64%	0.10%	1.45%
EFV	83.57%	15.48%	0.00%	0.95%
Elbow	70.65%	29.35%	0.00%	0.00%
End Cap	68.42%	30.53%	0.00%	1.05%
High Volume Tapping Tees	0.00%	100.00%	0.00%	0.00%
Pipe	0.00%	94.05%	5.95%	0.00%
Reducer	58.33%	37.50%	0.00%	4.17%
Riser	60.16%	39.84%	0.00%	0.00%
Service / Valve Tee	33.33%	55.56%	11.11%	0.00%
Service Saddles	0.00%	100.00%	0.00%	0.00%
Tapping Tee	87.50%	10.61%	0.47%	1.42%
Tee	5.00%	95.00%	0.00%	0.00%
Transition Fitting	0.00%	87.50%	12.50%	0.00%
Valve	22.22%	77.78%	0.00%	0.00%

Source: LocusView Solutions

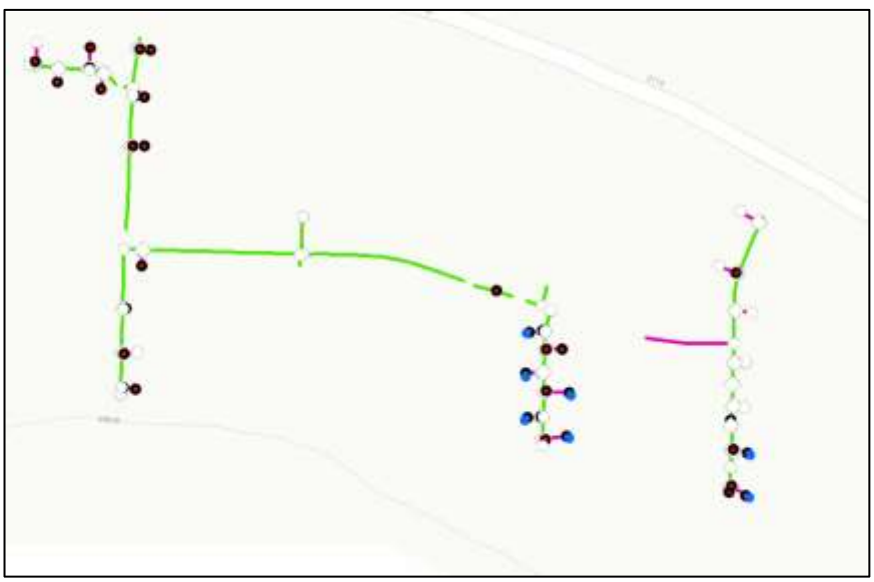
Qualitative Analysis

LVS regularly reviewed the collected data for qualitative accuracy and completeness and compiled a weekly report for PG&E that included a detailed analysis of the data collected for each project. Figure 10 and Figure 11 are examples of main and service installation data collected during the pilot project. The legend for the two figures is shown earlier in Figure 9.

Figure 10: Service and Main Installation Collected by Pacific Gas and Electric Company User on 8/16/17 in Oakley, California

Source: LocusView Solutions

Figure 11: Data Collected by Pacific Gas and Electric Company User in July and August 2017 in Walnut Creek, California



Source: LocusView Solutions

The project team was not able to obtain quantitative data on time savings for field data collection through use of the HAM technology because historical data on the amount of time needed to manually collect field data was not available. Field users, however, provided feedback indicating the technology reduced the amount of time required to create maps by eliminating the minutes needed to sketch the installation by hand and manually fill out paper forms, versus the few seconds needed to collect pipe and fittings data using the HAM technology.

Field Support Summary

LVS conducted weekly status calls to monitor and review the data collection process, address issues, answer questions and gather user feedback. LVS also provided a local field resource in the San Francisco Bay Area to provide training, technical support, and gather feedback from all users. Additionally, LVS supported 104 helpdesk requests throughout the project.

LVS's local field resource compiled a weekly report on observations obtained by shadowing users in the field and summarizing their feedback on the workflow and use of the system. Most feedback related to suggested hardware improvements, mapping application workflows, Bluetooth/RTK/Scanner connectivity issues, and questions on how the technology will be used moving forward.

The helpdesk calls averaged 6.6 minutes and were mostly related to issues with device connectivity, uncharged hardware, and pushing updates for software.

Issues, Modifications, and Improvements

LVS provided monthly software updates based on planned product improvements, enhancement requests from PG&E, and bug fixes. The initial release exhibited issues with Bluetooth and GPS/RTK connectivity in the field. A second release two months later included many improvements to the Bluetooth handling, as well as the user interface to allow the user to see if the GPS was performing correctly. These modifications led to significant improvements in GPS accuracy of the field collected features. There were 110 modifications made to the software and delivered to PG&E to address defect and product enhancement requests.

Enhancement requests were organized into configuration updates and core code updates. Configuration updates included changes to the materials list, field sorting, and labeling. Core code updates included changes to the user interface (symbology, font size) and functional changes, such as alterations in the workflow and how the information was displayed in the application. LVS created a new workflow process to map pipe that was installed using a "trenchless" method (such as horizontal directional drilling) that allows pipe to be mapped outside of the trench prior to installation and then moved to the new location once installed.

The RTK base stations were upgraded with equipment and operating systems for improved quality and a reduction in downtime. LVS created and provided weekly uptime reports to PG&E with an analysis of the root cause of system downtime. Most downtime issues were tied to the cellular systems.

Field users commonly experienced problems with uncharged equipment that prevented the use of the HAM technology. To address the issue, LVS redesigned the equipment carrying case to allow hardware components to be charged using a single wall plug instead of requiring the user to remove each component for separate charging.

Onsite Technology Demonstration

In April 2018, PG&E hosted a field visit to demonstrate live mapping in a real-world environment using the HAM units. Energy Commission project managers, LVS staff, and PG&E's R&D and Innovation staff, General Construction Foreman, Field Engineering Supervisor, and field engineers were present during the demonstration.

LVS demonstrated the equipment and functionality of the software outside of the construction area (Figure 12).

PG&E's crew then demonstrated the use of the HAM unit in an open trench on an actual facility (Figure 13). HAM unit users provided positive feedback regarding the technology and specifically commented on ease of use and elimination of paper sketches or redlines, and provided commentary as they mapped the fittings and pipe features.

Figure 12: LocusView Solutions Staff Demonstrates High-Accuracy Mapping Technology

Source: LocusView Solutions

Figure 13: Pacific Gas and Electric Company Staff Demonstrate Live Mapping

Source: LocusView Solutions

CHAPTER 3: Situational Awareness Tool

One of the primary objectives of this project was to develop and test a situational awareness tool to give the utility a process for pulling in data from disparate sources and presenting this information to a user in a common format. This common operating picture is valuable in making real-time assessments of potential emergency situations as they occur. The ability of an application to assist in coordinating efforts among multiple resources is important when addressing emergency or other situations and provides the situational awareness necessary for successful resolution.

Day-to-day users are those who typically work in an office setting but periodically need to go out into the field. The situational awareness application built for this project could satisfy their needs as it provides real-time information that is vital in understanding the environment in which an employee might find himself or herself. This type of application allows users to understand the activities they will be encountering before they get to a location. The users can then prepare accordingly and ensure they are aware of any safety issues they might encounter.

In the case of an emergency, the situational awareness application can provide important data and allow coordination of efforts to address and appropriately respond to the incident. Additionally, situational awareness can be a valuable tool in allocating resources to the appropriate location at the appropriate time. Situational awareness tools can be configured to manage these interactions and ensure resources are managed efficiently.

Design and Development

Gas Technology Institute (GTI) worked with Pacific Gas and Electric Company (PG&E) to develop a Use Case, functionality requirements, and a demonstration and testing plan for the situational awareness tool. Using information gathered from PG&E, GTI subsequently developed a set of application requirements as the basis for the situational awareness tool.

GTI chose the Environmental Systems Resources Institute (Esri) Web AppBuilder (developer edition) as the platform for developing the situational awareness application. This platform provided a singular application that would be viable for both mobile devices and Web-based applications. Once the application was configured, it was hosted on GTI's Amazon Web Services environment to provide the most efficient access and security for the application.

GTI planned to develop a technology-based approach using Esri's GIS technology that would leverage the hardware demonstrated as part of the high-accuracy mapping (HAM) segment of the project. Using hardware that was already being demonstrated would enable field users to readily access the situational awareness application.

GTI proposed a Use Case to PG&E in which a Web application would be developed to combine data from multiple data sources based on a geographic information system (GIS). This data included freely available information on hospitals, schools, police and fire resources, and other administrative boundaries. Additional information vital to situational awareness, and previously not available in PG&E applications, included real-time HAM data and real-time excavation location data. This information can provide important context for ongoing response to an emergency. GTI and PG&E also included transmission main GIS data provided by PG&E.

The application developed to support the Use Case was intended to include functionality to interact with the data, obtain information about proximity to high-risk and sensitive assets within the PG&E service territory, and include user-defined data to support emergency response situational awareness. The application would be built to allow the user to access “widgets” (an application or component of an interface that enables a user to perform a function or access a service) within the application to use functionality to support analysis.

The application was Web-based to provide the most accessible version of the application. The Web-based application also allows multiple clients to access the application and provides a consistent feel across various operating platforms.

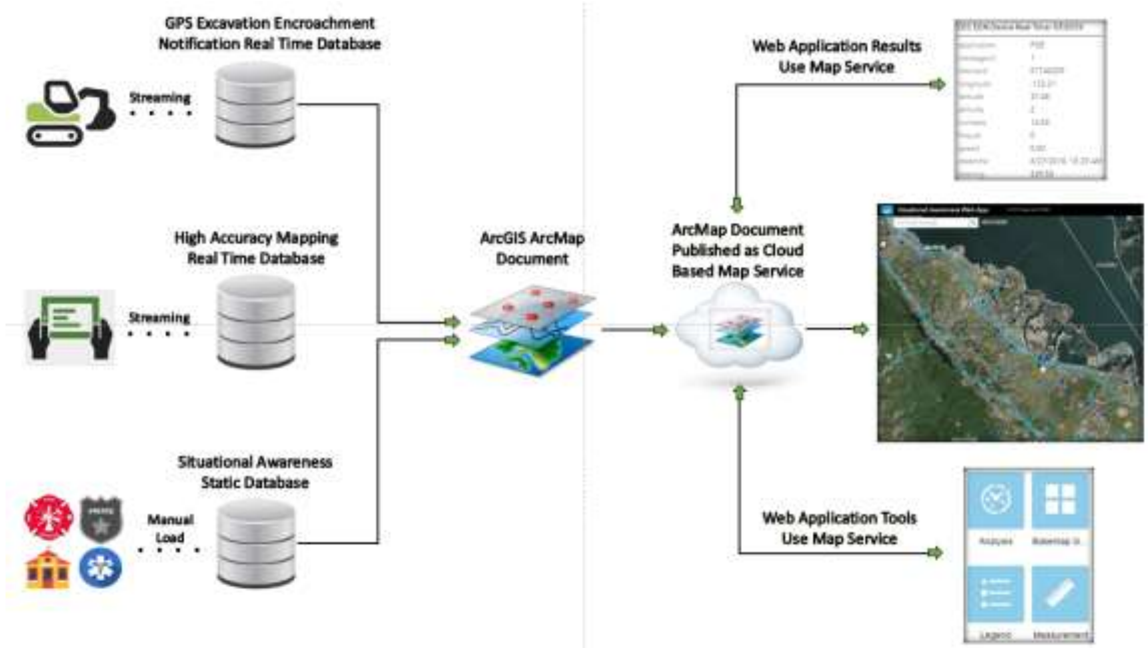
Configuration

The configuration for the situational awareness Web application has many components (Figure 14). The tool is built on the Esri platform which provides the ability to integrate many features and geospatial services. GTI launched an Amazon Web Services instance using Cloud Formation Templates developed and provided by Esri. Cloud Formation Templates allow the user to launch computing services with pre-configured software already installed. For this specific instance, Esri’s ArcGIS Server was installed to be the engine for creating and storing spatial data in a Microsoft Structured Query Language (SQL) server database, as well as the host for spatial Web mapping services. Web mapping services allow the user to create a map or data and then publish it for use on the Web. In the case of the situational awareness Web application, map services were published to display static data (for example, locations of schools and hospitals). The Web feature services were used to publish the dynamic data that can be updated in real time (for example, excavation equipment movements and utility data collected in the field using high-accuracy global navigation satellite system [GNSS] receivers).

Once these map/feature services are created and stored in the ArcGIS server, they are then available to be combined into a single map. GTI used the ArcGIS.com website to combine the data sources into a common map. The ArcGIS.com website functions as a location for users to create and save Web maps that they will use to share with certain users and applications. Not only does this platform provide a suitable place to construct and save maps, it also allows the user to implement security around the sensitive data. Permissions can be granted or denied to a user on any specific layer of the map or even the whole map, if needed.

After a Web map is built, the user can then create a Web application using the templates provided by Esri. The template that GTI chose was specifically built for situational awareness. To use the template and build a Web application, GTI use the Esri Web AppBuilder for ArcGIS (Developer Edition). Additional configuration was performed to get the Web application registered with the ArcGIS online account as well as lock down a continually running instance of Node.js in the background. Node.js is an open-source JavaScript engine that produces dynamic Web pages and is the application that the Developer Edition runs on.)

Figure 14: System Configuration Diagram



Source: GTI

Datasets

Based on discussions with PG&E and typical data used for situational awareness, GTI incorporated the following datasets into the application:

- Hospitals
- Police stations
- Fire stations
- Schools
- Real-time excavation encroachment devices (Provided from data collected in the CEC Excavation Encroachment Notifications project)
- HAM data (Collected for the current project by LVS)
- Aerial imagery (web-mapping application allows users to interactively select the basemap they want to use)

Functionality

After configuration was complete, GTI began to construct the situational awareness Web application with the proper tools following the intended use cases. Many out of the box widgets were used as well as one (Identify Widget) from the Esri developer community. The functionalities of the Web application and the widgets were tested and configured to arrive at a final version ready for PG&E user acceptance and field user testing. Once the Web application was developed and configured, GTI demonstrated the application on GTI's Amazon-based Server. This was to maintain the application and provide a friendlier Web address used for accessing the application.

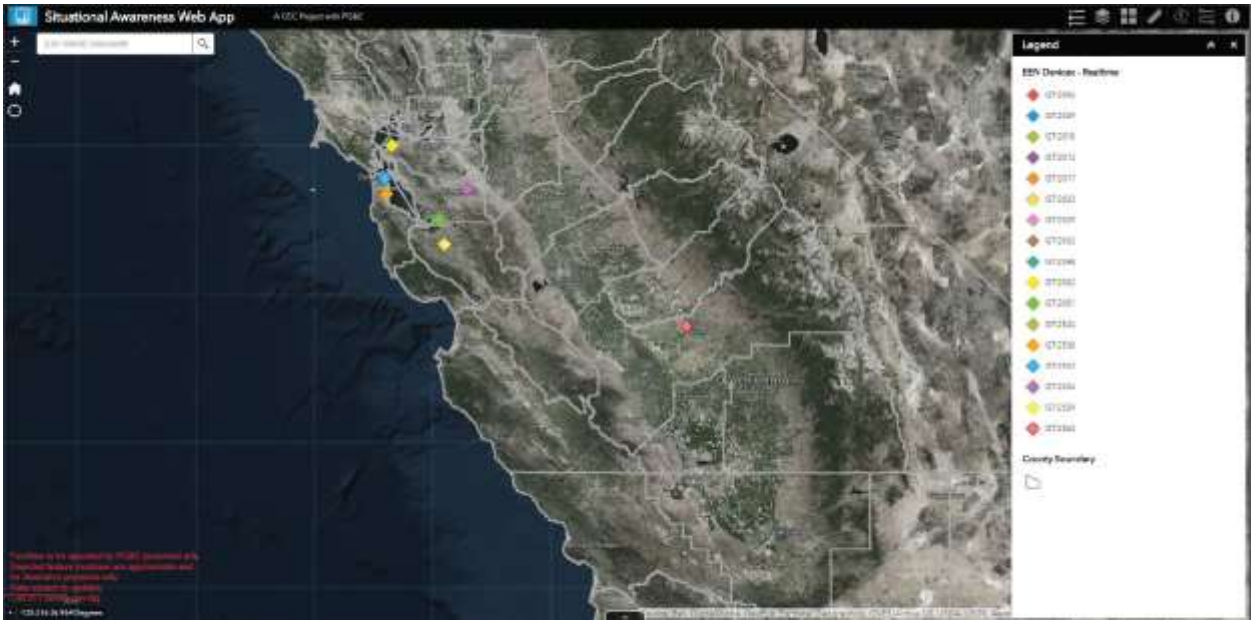
The tools within the situational awareness application are intended to help users of the application be more aware of their surroundings and make informed decisions based on the data and tools provided to them. The application only demonstrates a subset of solutions that can be derived from the data within the application. The main objective was not only to demonstrate the usefulness of the current state of the Web application but to also show that this application can easily be expanded to handle additional datasets and more specific user defined tools to meet a specific situational objective.

Each user has a unique login to access the application. Figure 15 displays what the user sees when first logging into the Web application. The application was developed to be simple to use and not overload users with data or activity when they first access the application. Different data layers, such as schools, hospitals, and newly installed assets collected with high-accuracy data GNSS, depend on the scale of the map and will only show when the user views maps at the county or city level. Having scale-dependent layers means data is only made available when the user zooms into a map, ensuring the application is not slowed down by users trying to access the data all at once. Figure 16 and Figure 17 show the map displays with data layers available at mid and full zoom levels. The data layers available through the application include the following:

- Schools.
- Hospitals.
- Fire stations.
- Police stations.
- Existing PG&E gas transmission lines.
- Real-time data feed of newly installed utilities from the high-accuracy GNSS mapping portion of this project.
- Real-time data feed of excavation equipment coming from a separate Energy Commission funded Excavation Encroachment Notification (EEN) project.
- County boundaries.

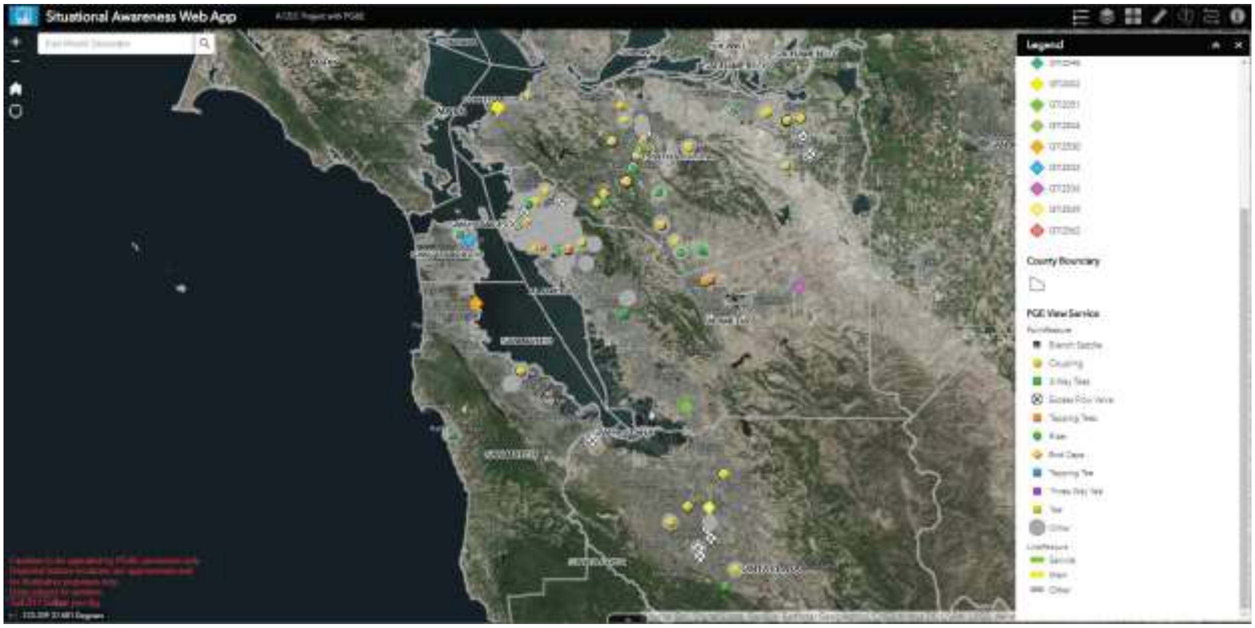
In the upper left hand corner of the application, the user can work with some of the simple tools to control the map. These tools are shown and explained in Appendix B.

Figure 15: Situational Awareness Web Application Initial Screen



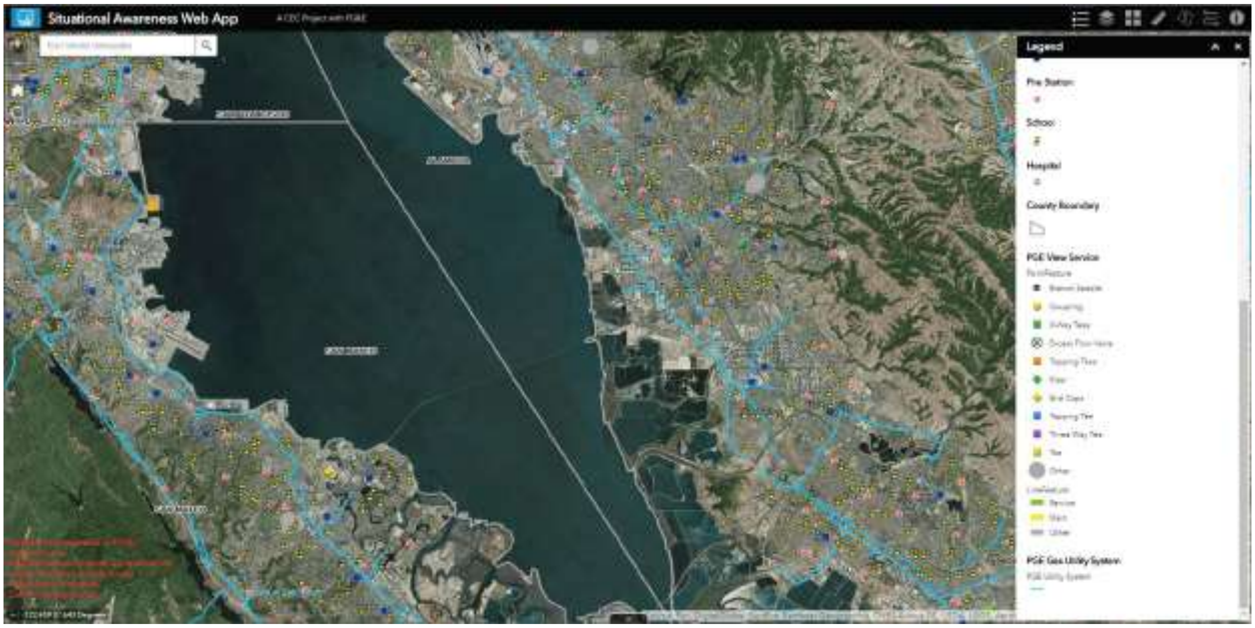
Source: GTI

Figure 16: Data Layers with Mid-Level Zoom



Source: GTI

Figure 17: Data Layers with Full Zoom



Source: GTI

Testing

This section discusses the user acceptance testing (UAT) plan developed by GTI for PG&E to test the situational awareness application's functionality, and the results of the testing conducted by PG&E staff.

Process and Metrics

The software and hardware was tested on site at PG&E's offices by a representative from GTI and members of PG&E's construction crews. Testing included the following applications and technology:

- Web application as configured and managed by GTI
- GTI Servers (Amazon-based GIS Services and Applications with Esri technology)
- Hardware (tablet)
- User Guides
- User Training

In testing the application, the following metrics were developed to ensure the application functioned as needed:

- Ability of the application to successfully display data on the screen 100 percent of the time
- Ability of the user to login successfully 100 percent of the time
- Consistent availability of data sources, including:
    - General location data (including hospitals, schools, fire services, police).

- HAM data from this project.
- Excavation Encroachment Real-Time Data (Excavation data as provided by GTI through the EEN project).
- Transmission gas data (Provided by PG&E and hosted by GTI).

Training

GTI created the following training tools during this project:

- Job Aid: Used by field workers to provide an overview of the functionality of the situational awareness tool (Appendix B).
- User Guide: Provided in-depth information about the functionality of the application (Appendix C).
- Webinars: Used to walk users through the application, demonstrate functionality, and address questions.
- Situational Awareness Overview Document: Provided a starting point for development of the situational awareness application and potential workflows (Appendix D).
- Workflow Diagram (Appendix E).

Demonstration and Testing

After completion of use cases and application development, GTI demonstrated the Web application to PG&E for UAT. To complete demonstration and testing, GTI worked with LVS to remotely reinstall the Safari Browser, which had previously been removed from the iOS devices being used for the HAM Pilot Project. A shortcut or bookmark to access the Web-based application was also added. GTI also supplied a UAT help document to walk the application testers through the use case of the application. In addition, GTI developed a job aid to provide end-users with a detailed description of the functionality of the application and information about accessing the application.

While the target devices and operating system for the purposes of this project was iOS running on an iPad device, the application was also tested on several other devices such as:

- Apple iPad Mini 4 (Apple iOS)
- Apple iPhone 6 Plus (Apple iOS)
- Google Nexus 5x (Android)
- Google Nexus 6P (Android)
- Google Pixel 2 XL (Android)
- Google Chrome Browser (Windows 10 OS)

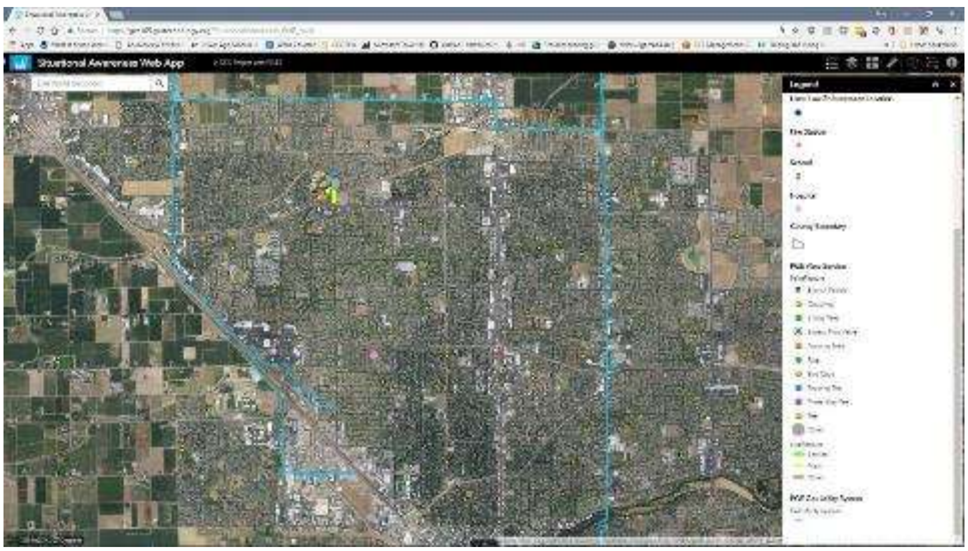
GTI also used application templates from Esri to provide specific functionality related to situational awareness within the Web mapping application. The Web mapping application included the functionalities described below.

Application Overview

The situational awareness application is accessed through a named user account to ensure access is only available to permitted users. Data layers are also scale-dependent to speed up display, especially when on a potentially slower mobile data connection; however, from a cartographic standpoint, scale dependency also provides the user with a visually easier-to-interpret map. In addition, the scale dependency allows for improved display when using a device with a smaller screen such as a tablet or smartphone.

Figure 18 displays the Web mapping application that the user would see as they navigate around the map. The available layers are listed on the right side of the application to provide a legend depicting the symbols and the name of the layers.

Figure 18: Situational Awareness Web Mapping Application



Source: GTI

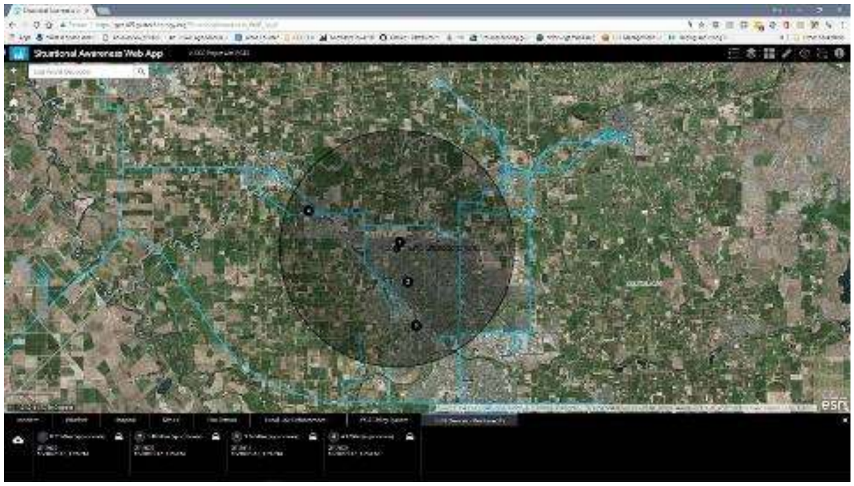
Situational Awareness Widget

The Situational Awareness Widget (SAW) is provided by Esri as a widget or additional functionality that can be added to a Web mapping template. The SAW is configurable based on data sources being pulled into the Web mapping application and provides specific functionality based on information related to proximity of resources and information that is useful for providing situational awareness.

The SAW allows the users to 'locate an incident' by dropping a pin on a location, drawing a line or drawing a polygon. Once the user defines the location, they can provide a 'buffer' to use as a filter to spatially located resources within that area.

In Figure 19, the user has selected a five-mile buffer and found the EEN devices within that boundary. It shows a screen shot of the data that is available and the corresponding location on the map. This data can be useful to provide awareness of excavation activity occurring with the immediate area.

Figure 19: Situational Awareness Widget - Realtime Excavation Encroachment Notification Devices



Source: GTI

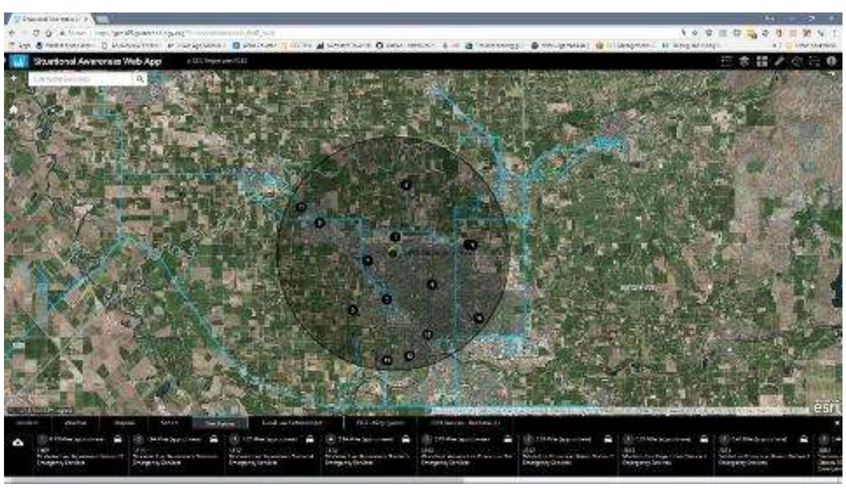
Figure 20 shows a zoomed in portion of the results available in the application, listing EEN devices within a specified radius.

Figure 20: Realtime Excavation Encroachment Notification Devices within Five Miles

Source: GTI

In another example of the SAW (Figure 21), the user can use the same five-mile buffer to view the fire stations within the boundary.

Figure 21: Situational Awareness Widget: Fire Stations



Source: GTI

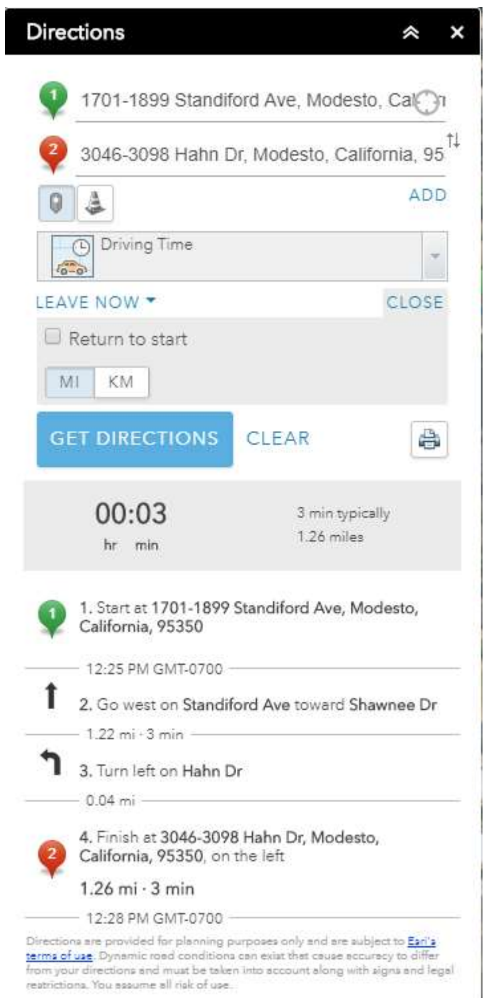
This provides the users with the location on the map as well as the distance and the address of the fire station (Figure 22).

Figure 22: Fire Stations within Five Miles

Source: GTI

By clicking on the fire station, the user can also have the application provide routing directions to travel to the station. The directions (Figure 23) provided by the application can be very useful in emergency situations. The data provided by the SAW can also be downloaded as a CSV file and used in a number of other applications.

Figure 23: Directions to Selected Fire Station



Source: GTI

User Comments and Issue Resolution

GTI provided PG&E with the situational awareness application and documentation in August 2017 for review and feedback. Documentation included the user acceptance checklist (Table 12), which has been updated with PG&E responses to the questions. The checklist was used to define and execute the functionality of the application and provide feedback for the expected functionality.

Through the UAT process, several issues related to the performance of the application and its functionality were identified. GTI worked with PG&E to address the issues that could be resolved. Certain issues identified by PG&E were the result of limitations of the platform or were made by design. Various webinars and conference calls were conducted to discuss the functionality and performance of the application throughout the UAT process.

Table 12: User Acceptance Checklist for Situational Awareness Tool

Task or Requirement	Pass	Fail	Comments.
Can you access the website from the iPad tablet/desktop/laptop Web browser?	X		
Were you able to login into the Web application?		X	Yes I was able to log in, but I should not have to type in my password twice.
Did the website load successfully after login?	X		
Were you able to pan and zoom the map?		X	If I zoom in too close, the application becomes very laggy to the point of unusability. Sometimes the webpage just completely freezes and I have to exit Safari, re-open it and log into the Web application again. There is also a lag on the laptop computer, but eventually the Web page recovers.
Were you able to see the gas utility pipe data in blue?	X		
Were you able to see the live stream of excavation devices?			Am I supposed to see these moving on the map? I can see the static icons.
After zooming into the county level were you able to see the HAM data?	X		
Were you able to click on the high-accuracy mapping data and retrieve information?		X	It's very difficult to do this on a mobile device (for example, fat finger problem) For fittings and parallel lines, in order to click on them to retrieve data, you have to zoom in very close. However, doing so causes the Web page to lag during the zoom in process and becomes unusable.

Task or Requirement	Pass	Fail	Comments.
After zooming into the street level did gas lines change color?	X		
Were you able to click these gas main to retrieve information?		X	It's very difficult to do this on a mobile device (for example, fat finger problem)
After zooming into the street level did schools, hospitals, etc. turn on?	X		The symbol for schools (yellow flag) is not intuitive. Can we change this?
Were you able to click these features to retrieve information?	X		
Were you able to locate an address using the World Geocoder?	X		
Were you able to locate and click on the various widgets?		X	Too difficult to see these widgets because they are translucent.
Were you able to turn layers on/off using the Layers List Widget?	X		
Were you able to review layer symbols in the Legend Widget?	X		
Were you able to change the map using the Basemap Widget?	X		
Were you able to measure distances using the Measure Widget?	X		It's very difficult to use on a mobile device
Were you able to access the Situational Awareness Widget?	X		It's very difficult to use on a mobile device Under the weather tab for the situational awareness widget, it loads perpetually. What data is supposed to be displayed here?
Were you able change the buffer distance, place a point and see the buffer get created with the Situational Awareness Widget?		X	When I tried placing a line, I could not end the line with a double tap. Same issue with the polygon. The point worked fine. What does buffer distance mean? When I used a 5-mile buffer distance and placed a line on my laptop, the radius it drew around the line was way more than 5 miles.
Were the results of the buffer analysis accurate?			Cannot verify this. Do not understand buffer distance.
Were you able to download a CSV file for each category (that is schools, fire stations) that retrieved a result? (desktop/laptop Web browser version only)	X		I should not get multiple files; a single file should include all of this data to be useful.
Were you able to use the driving directions option within the Situational Awareness results to get directions to and from the incident?	X		

Task or Requirement	Pass	Fail	Comments.
Were you able to click on the Incident Tab of the Situational Awareness Widget and then click on Start Over?	X		
Were you able to access the Directions Widget?	X		For directions, can you explain the difference between "rural driving", "driving" and "trucking"?
Were you able to type in to and from addresses and retrieve directions?	X		
Were you able to add in stops to your route while using the Directions Widget?	X		
Were the directions retrieved accurate to the stops you added?	X		
Were you able to add in barriers to your route while using the Directions Widget?	X		
Were the directions retrieved accurate to the barriers you added?	X		

Additional comments

Can we make the usernames the same as the users LAN IDs? Moreover, can we use an easier password for the purpose of the pilot?

Can the user access an offline version of this tool if there is no cell coverage?

This will not work in low cell coverage area. Even with a good WIFI connection, there are lags.

Buttons and text need to be significantly larger for the mobile device. It is not construction crew friendly.

Overall, this is not a mobile friendly tool. Due to the issues mentioned above, it does not provide a benefit to the crews. What is needed is a native mobile application. The tool is OK on a laptop/desktop computer.

UAT completed by:	PG&E User	**Date completed:**	9/12/17
Test case outcome: *circle appropriate outcome*	**Satisfactory / Pending clarification / Return to developers**		

Source: GTI

The feedback provided by PG&E identified several issues. Some issues could be addressed within the scope and timeline of the current project, while others could be addressed with development of business and functional requirements, which would be typical of a commercially developed application. The issues and resolution provided by GTI are listed below.

Issue #1, Logging into the application

Problem: The architecture of the system requires the user to enter the username/password twice.

Resolution: Unfortunately, there is no way around this. Due to the short duration of the pilot project, it would not be feasible to build a solution in which the architecture could accommodate using only one login. The data/Web application reside on different servers requiring their own authentication.

Issue #2: Slow response of application

Problem: When the user zooms in, the application is slow and the data takes a while to display.

Resolution: Some modifications of the scale dependency were made to provide a better end user experience.

Issue #3: Live data

Problem: PG&E inquired about the streaming data from the real time excavation device layer.

Resolution: GTI controls how often the data updates – it was set to update every four minutes. This is a configurable setting and can be changed. For this project, this seemed reasonable.

Issue #4: Ability to click on HAM data

Problem: PG&E found it difficult to select items within the HAM dataset.

Resolution: GTI modified the symbology to make the items much larger resulting in a larger touch target when using a mobile device. This is an easy change to make and provides a much larger target to identify data.

Issue #5: Symbology for schools

Problem: Symbol for schools was not intuitive.

Resolution: GTI changed the symbology to provide more information about the type of feature. This was an easy change to make.

Issue #6: Difficulty seeing widgets

Problem: The widgets on the Web application utilized to access the applications functionality were difficult to see due to the color/transparency.

Resolution: GTI moved the widgets to the header of the title bar so they would be easier to see against the black background.

Issue #7: Difficulty using the SAW buffer functionality

Problem: When PG&E tried to create a buffer using the line or polygon on the SAW tool, it was difficult to create the line or the polygon on the tablet.

Resolution: GTI was able to reproduce some of the issues with this tool. The point tool works fine on mobile devices. The line and polygon was hit or miss. GTI advised using the point feature on mobile devices and using the line or polygon on desktop devices. GTI will incorporate this information into the user documentation.

Issue #8: Use of LAN IDs

Problem: PG&E inquired about using their enterprise logins on the mobile devices for the situational awareness application.

Resolution: While this is feasible, it would not be possible within the 60-day pilot project. There are many security issues with ensuring that this is done correctly.

Issue #9: Offline use

Problem: PG&E inquired about using the application when offline or without a data connection.

Resolution: This pilot project was intended to only support on-line connections and did not have any provisions for being able to cache data to use in the event there was no cellular coverage. This would technically be feasible, but not within this project.

Issue #10: Button size

Problem: Buttons and text need to be significantly larger for construction crews.

Resolution: All mobile devices have the capability for the user to modify the text and button size in the settings of the device. GTI was able to increase the size to a more acceptable proportion for the field users.

Other End-User Feedback

Overall, PG&E assessed the application is not optimized for use on mobile iOS devices. Many of the issues with usability were addressed to the extent they can be in the web-based application. Some of the other issues could be potentially mitigated in a native iOS application, however this would require addressing the restrictions that Apple has on development and deployment of iOS applications. Development would require a Mac computer, iOS/xCode registered developer and approval by the iOS App Store in order to push an application to users in the field. While development of a native iOS application is completely feasible for a commercial scale application, utilizing a more flexible platform, such as the Web mapping application, was believed to be more practical for purposes of the current project.

Both GTI and PG&E identified an issue relating to the users of the application. The type of data used for situational awareness and the processes required to act on this type of information are not typically expected of the field users that had been identified to be the end users of this application. The field users who were identified to collect HAM data were supposed to use the situational awareness application. However, after user testing, it became clear to both PG&E and GTI that the originally intended users would not benefit from the situational awareness application. In addition, the resources from PG&E that used the HAM system had very limited time to collect the mapping data and did not have time to test the situational awareness application with any regularity.

The most successful portion of this project has been the integration of different data sources from different processes and data collection efforts into a single application. This can benefit a utility because it provides increased awareness about construction activity taking place within the utility's service territory. It is generally difficult to integrate data from multiple sources, especially in real-time since data exists in different silos and requires knowledge of each system and assimilated access to these resources. This project has proven that it is possible to pull these data sources together using GIS as the common platform.

Based on the results of UAT, GTI made changes to the situational awareness Web Application to maximize benefit to PG&E. GTI and PG&E also discussed the best opportunities to integrate the concept of real-time data with other systems at PG&E, including the Tactical Analysis Mapping Integration (TAMI) system and the Gas Operations Control Center. Integrating the real-time data with applications like TAMI may be invaluable in leveraging the investment in GIS and providing safety to the entire natural gas system and the public that can be impacted by outages and potential life-threatening damage to the natural gas system.

Situational Awareness Survey

To better understand the gas utilities' needs and current efforts relating to situational awareness, GTI surveyed approximately 30 gas utility companies in North America. The short survey focused on how technology and specifically GIS is used in each gas utility's situational awareness program. In addition, the survey discussed the solution developed by GTI for PG&E to determine interest in future efforts related to situational awareness capabilities.

GTI received responses from eight different gas utilities. About half of the respondents indicated their utility employs some sort of technology platform to manage its emergency response. Almost 90 percent of gas utilities use at least some GIS technology for their emergency response, with 62.5 percent of utilities indicating they use "a lot of GIS data." To gauge the utilities' interest and plans for using a technology-based approach for situational awareness, GTI described the solution developed for PG&E and asked if that was of interest. Three quarters of the respondents indicated they would be interested in a solution that provided those capabilities; however, such a solution would need to be highly customized for their business process and integrated into their enterprise GIS. Based on these responses, it was clear the utilities are planning on developing and integrating more data and GIS technology into their emergency response plans.

CHAPTER 4: Technology Transfer

Technology Transfer Plan

The high-accuracy mapping (HAM) technology developed in this project will be commercialized by LocusView Solutions (LVS) with support from the Gas Technology Institute (GTI). The situational awareness tool requires further development and end-user testing.

Targeted Market

The target markets for the HAM technology include natural gas infrastructure operators (distribution and transmission), other critical infrastructure operators in the United States and Canada, and companies that provide mapping services to natural gas system operators.

The size of the total addressable market for the natural gas distribution industry in the United States is estimated as 6,000 field crews. This estimate is based on a market study performed with three operators that provided an estimated ratio of 0.0015 users per mile of pipe. The ratio was extrapolated for 4 million miles of natural gas distribution and transmission pipeline to calculate 6,000 total users in the United States.

Trends Affecting Market Demand

Regulatory

Department of Transportation regulations for natural gas integrity management provide an incentive for operators to use technologies that improve and increase data collection, with a specific focus on mapping and traceability data. This trend is expected to continue as new federal and state regulations are enacted.

Technology

The technology to make field collection of HAM data efficient for utility companies is now available. Tablet computers and mobile geographic information systems (GIS) provide the foundation for cost-effective data collection systems that require minimal skills and training. New functionality from consumer grade technology used by utility companies and their decreasing costs are trends expected to continue.

Standards

Standards for hardware interfaces, communication protocols, and mapping systems allow creation of flexible and modular systems that can be interchanged to create systems specific for the utility industry.

Potential for Market Share

The project team has developed a system to leverage existing technology but provide customized functionality for the natural gas industry. The team expects half of the largest natural gas distribution companies in the United States that have more than one million meters to conduct pilot projects of this technology by the end of 2019. LVS has already conducted pilot testing with 10 pipeline operators.

The Energy Commission's support for the implementation of this technology at Pacific Gas and Electric Company (PG&E) has provided the credibility and case study for further deployment in California and throughout the United States.

Marketing Plan

The project team will use the following activities to market and sell the technology:

- Demonstrations and presentations at industry events including the American Gas Association's Annual Operations Conference and the Western Energy Institute's Operations Conference.
- Exhibitions at industry conferences including national and state trade association shows.
- Advertisements in trade journals including American Gas, Pipeline Gas and Journal, and the American Public Gas Association's publication The Source.
- Information webinars and Web demonstrations.
- Quantified risk reduction estimates to support business case development for utilities.
- Partnerships with information technology consulting firms to provide a holistic solution that integrates with other information technology systems.
- Partnerships with field services companies that can provide HAM as a service

LVS will have primary responsibility for marketing and selling the HAM technology. LVS's Chief Executive Officer Alicia Farag led the development and commercialization of two other similar products: Distribution Integrity Management Program Risk Model and GPS-Enabled Leak Survey Solution. The leak survey solution (https://www.locusview.com/products.html) is in use by more than 10 operators. LVS will also use regional channel partners to target medium and small operators.

Barriers to Deployment

Technology implementations that require changes to workflows and business processes are complex to implement and can result in failure because supporting systems are not in place. The team will use phased implementation with validation points to ensure the workflows and business processes are robust and fully tested prior to moving to the next stage of implementation. Phased implementation in defined geographic regions can also ensure success is achieved on a small scale before continuing implementation throughout the entire organization.

Technology implementations that are not linked to a strategic technology roadmap and do not have executive level support can lose the momentum needed to be successful. The solution to overcome this potential barrier is to develop a project charter to clearly link executive supported roadmaps and goals. It is also helpful to have an executive project "champion" who agrees to support the project through completion. Specific barriers include:

- End-user acceptance: The typical end-user of the new mapping technology is a construction crew member with limited exposure to mobile applications for field data collection. While some users are able to learn the technology very quickly, others may be uncomfortable and unfamiliar with mobile applications and devices. Further, the use of high-accuracy global positioning system (GPS) technology requires the user to constantly monitor and adjust for environmental factors that affect accuracy, such as tree canopies or buildings.
- Contract workforce: Utility companies typically perform construction operations using contractors. Implementing new technology can add to contractor's responsibilities and costs not covered under existing agreements and cost structures.
- Legacy business practices: Utility companies have built business practices over decades based on manual and paper-based data collection. Implementing high-accuracy mapping with mobile applications has implications for these legacy business practices and requires significant change management to fully realize the benefits of new technology.

Cost

The primary motivations to implement this technology are regulatory compliance, risk reduction, and public safety. Companies have also identified automation and efficiency benefits that will help build the business case for the technology. Cost does not appear to be a primary competitive factor. Furthermore, the technology has custom features developed specifically for the natural gas industry and are not available from other technology providers. Examples include applications for traceability of fusion/welds, operator qualification verification, and pressure test records.

The estimated purchase price of the technology is $25,000 per unit including hardware, software, and configuration services. This price is based on input costs and the price of existing solutions that start at $30,000 per unit for similar levels of mapping accuracy.

The upfront purchase price is the most significant cost element of the solution. Some hardware components will need to be replaced every three to five years; however, the GPS receiver (which is the most expensive component) has a life of five to seven years.

Large deployments at companies such as PG&E should result in cost savings of approximately 30 percent. These savings will be achieved through bulk hardware purchases and volume discounts on software. The costs for tablets and GPS receivers are expected to continue to decrease in the next five years to provide further reductions in system costs.

Financial Plan

The initial funding for the development of this technology was provided by Operations Technology Development (OTD). PG&E, a member of OTD, was a strong supporter of the development of this technology and contributed funds to support its initial development. The project team anticipates that OTD and PG&E will continue to financially support the implementation and further development of this technology. Beyond this, the team can seek funding from the Department of Transportation Pipeline and Hazardous Materials Safety Administration and other operators who are also interested in implementing this technology.

Growth Highlights

The team has successfully commercialized a product for GPS-Enabled Leak Survey. This solution is being used in a production environment by several operators, and other implementations are planned for 2018-2019. The team has also successfully commercialized a tool for "intelligent inspections" using mobile applications and advanced visualization tools to identify trends in quality issues. The Intelligent Inspection has been rolled out to four gas utilities, with several more slated for 2018-2019. Additional information is available at LVS's website (www.locusview.com).

To support the commercialization of technologies, GTI formed LVS to provide commercial scale implementation services for mobile and GIS technologies. Since its formation in 2014, LVS has launched several new products with utility companies. The GTI-LVS roadmap includes the continued development of technologies to support mapping and integrity management for the natural gas industry. To support the implementation of the HAM and visualization technology, LVS has hired additional personnel and has formed a partnership with GTS Engineering and Consulting (http://www.gtsinc.us) to support expanded implementation at PG&E after a successful full-scale pilot project. LVS plans to roll out the HAM solution to production at several gas utilities in 2018.

Technology Transfer Activities

The following describes specific activities in regards to transferring the HAM technology to the market.

- Presented at industry events, American Gas Association's Annual Operations Conference,[4] ESRI GeoConX conference,[5] and Western Energy Institute's Operations Conference.

---

[4] http://proceedings.esri.com/library/userconf/geoconx17/papers/geoconx_24.pdf.

[5] Paperless As-Builting and High Accuracy GPS at PG&E . . . Beyond Material Traceability, Alicia Farag, AGA Tracking and Traceability Workshop, Pittsburgh, PA, Oct 17-18, 2017.

- Advertised in trade journals including American Gas Magazine and the Pipeline and Gas Journal.[6]
- Worked with PG&E towards transitioning the HAM technology to a production environment, including:
    - Conducted information webinars and Web demonstrations to other PG&E stakeholders including executives, and staff representing engineering, integrity management, and construction.
    - Developed a plan, schedule, and budget for full production deployment.
    - Provided updated equipment and training and conducted stakeholder workshop for transitioning the technology from R&D to preproduction to production environment at PG&E.
    - Reviewed the condition of existing equipment, replaced damaged parts, and provided an additional inventory to allow replacement throughout the transitioning activity.
    - Delivered a new software application with end-user requested modifications based on the pilot project results, including additional quality control and ease-of-use features.
    - Developed a workflow for integrating data into the enterprise GIS and criteria for removing paper forms and records.
    - Provided training and technical support to end-users.
    - Discussed a plan to transition HAM technology to a live full-time production environment.
    - Delivered a pre-production application with new features and updates requested by PG&E after the pilot project.
- Spoke to nearly 50 American Gas Association member utilities about the HAM technology during their tour of the GTI facilities in April 2018.
- Updated description of the technology on LVS website (www.locusview.com).

[6] https://pgjonline.com/2017/10/20/asset-tracking-and-traceability-field-to-gis-solution/.

CHAPTER 5: Benefits to California

This project demonstrated a system that creates and display high-accuracy maps of underground natural gas distribution assets to reduce incidents of excavation damage and the amount of time required to locate assets for engineering, operations, and one-call activities thus reducing overall operational costs to the utility. Compared to currently available technologies, the system decreases the amount of time to get field data into the enterprise mapping database, improves the accuracy and completeness of collected data, and allows data to be collected by field construction crews during routine operations. The system will be commercially available upon completion of the project without the need for significant additional effort. The mapping data has also been incorporated into a situational awareness tool to provide real time information on underground distribution assets and excavation activity.

The high-accuracy mapping data reduces the potential for excavation damage to the natural gas system and improves situational awareness during routine system operations as well as emergency events. Additionally, reducing the time and manual interaction required to obtain potentially important gas system information can decrease system outage times and prevent potential adverse impacts to the gas system and the public. The situational awareness tool offers the utility a common operating picture at any point for more functional communications and planning and, ultimately, a more efficient and safe operation.

Specific benefits to California are discussed below.

Energy and Cost Savings

The project team estimates there are more than 2.5 million excavation calls and about 600 excavation damage events each year in California, resulting in an average gas release of around 40 thousand standard cubic feet (Mscf) and average damage of $5,000 per event. Once the high-accuracy mapping (HAM) technology is fully implemented and global navigation satellite system data incorporated into the geographic information system, Pacific Gas and Electric Company (PG&E) assumes the HAM technology will assist in reducing the excavation damages resulting from inaccurate location of underground assets by more than 50 percent throughout PG&E's service territory. If fully deployed, the technology is expected to eliminate 300 excavation damage events annually in California, which translates into annual reductions of about 11,700 Mscf in natural gas release and $1.5 million in excavation damage costs. Additional energy savings would result from reduced use of equipment to transport personnel and repair equipment as well as from reduced onsite use of repair equipment.

High-accuracy maps can also reduce the amount of time required to locate assets for engineering, operations, and "call before you dig" activities, thus reducing overall operational costs.

Emissions Reductions

The HAM technology can reduce emissions of natural gas by 11,700 Mscf annually. Additional emissions reductions would result from reductions in use of equipment for transportation of personnel and repair equipment as well as in onsite use of the repair equipment as a result of fewer excavation damage events. Because methane is the primary constituent of natural gas and is a potent greenhouse gas, reducing emissions from the natural gas system contributes to California's air quality and climate change goals.

Non-Energy Benefits

The HAM application improves the accuracy and quality of traceability and geographic data collected in the field. Utilities will be able to easily and efficiently map natural gas assets when they are installed to within inches of accuracy and have access to the data in real time. High-accuracy maps will assist in more precisely locating specific assets that must be repaired or replaced in the future.

The situational awareness tool provides information in real-time that might not typically be available to personnel in the field. This information can allow the user to be more informed about the activities around them and act upon information they would typically not have available to them. The tool can greatly improve the response times and in some cases resolve situations before they reach the stage of being an emergency. At this time, sufficient data is not available to estimate average reduction in response time.

CHAPTER 6: Conclusions and Recommendations

The high-accuracy mapping (HAM) technology offers a viable tool to gas utilities in the United States to more accurately map their underground assets by utilizing commercially available equipment through use of advanced software, configuration, and measurement techniques.

The HAM technology demonstrated and tested in this project has the potential to map more than 90 percent of the underground plastic pipe and fittings assets accurately to within 6 inches of their actual locations. Future performance enhancements of commercial equipment, equipment configuration, and data acquisition and processing software has the potential to increase this accuracy. Through more accurately mapping of assets, the technology has the potential to eliminate 300 excavation damage events annually in California, which would translate into annual energy, cost, and emissions reductions of about 11,700 Mscf of natural gas released and $1.5 million in excavation damage. Additional energy savings would result from reductions in the use of equipment to transport personnel and repair equipment, as well as the onsite use of repair equipment, as a result of fewer excavation damage events.

The situational awareness tool developed in this project consolidates relevant data from multiple sources in a Web based application. It offers the utility a common operating picture at any point for more functional communications, planning, and ultimately a more efficient and safe operation.

The project research team offers the following conclusions and recommendations for future activities based on its experiences in developing, demonstrating, and testing the HAM technology and the situational awareness tool.

High-Accuracy Mapping Technology

Conclusions

- Recent advancements in technology enabled the project team to demonstrate and test software and hardware that makes it feasible for utility construction personnel to collect high-accuracy global positioning system (GPS) data to create maps and records of underground assets. Users require moderate initial training and consistent technical support to effectively implement the mapping system. Based on the pilot results and monitoring of data accuracy, the project team concludes the average users need one to two weeks of field use after training to become proficient with the technology. This conclusion is supported by the increase in data accuracy demonstrated within the first month of usage. Users with a strong technology background may be effective immediately after training.
- User interface and ease-of-use are important for end-user adoption. The project team continuously refined the software interface to make it more intuitive and efficient to

use. The team also made changes to the hardware to support durability and ergonomics. Feedback provided by the end-users confirmed that improved user interfaces with more intuitive reporting of GPS accuracy resulted in collection of higher accuracy data. Improvements in the hardware also ensured that all equipment was properly handled and charged at appropriate intervals, ensuring effective usage throughout a workday.

- In certain environments, it is not feasible to collect high-accuracy GPS data. Obstructions like buildings and trees can cause accuracies to drop to more than 12 inches. This conclusion is supported by the lower accuracies achieved when users mapped services and risers located near buildings. With new technologies being implemented, like laser range finders for location offsets, and with more satellites being placed into orbit, these limitations could be minimized in the near future.
- Automated data collection through barcode scanning creates efficiencies in the field and in the office. Approximately 50 percent of assets were mapped through barcode scanning, 45 percent were mapped through selection from a material list, and fewer than 5 percent were entered manually. Scanning an asset barcode to capture material attribute information needed for mapping greatly reduced the time needed to enter data compared to the existing method of manually writing that information properly on a paper form and/or a sketch drawing. Although the project team was not able to capture quantitative metrics of time savings, qualitative user feedback confirmed that scanning barcodes was significantly faster than manual documentation.

Recommendations to Improve the System

- Identify opportunities to remove paper forms and records from the field data collection process: To create the desired efficiencies, the HAM software could be expanded to collect other data that is currently collected on paper forms and records. Removing paper from the field process requires further testing and validation to ensure the data required for regulatory compliance and company standards is accurately collected electronically.
- Purchase new assets with ASTM material traceability barcodes: Approximately 50 percent of mapped assets at PG&E were created through barcode scanning. To provide greater efficiencies and quality of data collection, utilities should consider increasing the amount of assets with material traceability barcodes.

Recommendations to Facilitate Implementation

- Build business processes to support the workflow of integrating field collected data into the enterprise GIS: Incorporate an efficient and seamless process for moving data from the Web Map into the GIS.
- Implement a formal change management program: Implementing high-accuracy GPS for mapping will affect various segments on an organization, including GIS, information technology, engineering, construction, integrity management, one-call locating, and emergency response. An effective change management program should include the following components:

- Communication plan including executive sponsorship, frequency, format, content, and feedback mechanisms. Techniques such as roadshows, forums, user groups, emails, flyers, and town hall style meetings could be included.
- Sponsorship from an executive to provide consistent reinforcement of the value and commitment to technology implementation.
- Training plan, including classroom and field training, user guides, frequently asked questions, troubleshooting guides, videos, and a helpdesk resource. The training program should include both field and office users.

Situational Awareness Tool

Conclusions

- GTI and PG&E held multiple discussions related to situational awareness and PG&E's ongoing development efforts. It is important to be cognizant of the work environment in which the technology is targeted to be demonstrated. The intended demonstration target was the field users who were already had the Apple iPad devices used for the high-accuracy mapping portion of this project. However, it was learned these users would not be expected to make decisions within the emergency response workflow at PG&E. This limitation was not a consideration when the initial scope of work was developed for this project. Therefore, it is important to accurately define expected product specifications and functionality, and assess the product's fit with the end user's business processes early on in the project.
- Due to PG&E's business processes related to situational awareness, the application developed by GTI was not tested in the field by PG&E. Instead, the tool was evaluated through limited testing of the application by PG&E's R&D and Innovation staff. Feedback from testing conducted by PG&E showed the situational awareness application has potential but would require usability improvements, compatibility with the utility's business processes, and buy-in from field users before it could be demonstrated in the field. The situational awareness application provided information not readily available to field users and could be leveraged to improve situational awareness. However, extensive training and new business processes would need to be developed to support this within PG&E's current workflows.
- As more data is collected in a GIS and made available through the tools provided by the GIS, there will be an ability to provide a robust set of tools to address emergency situations in the field and provide a common operating picture at any point. This will allow for more functional communications, planning, and ultimately a more efficient and safe operation of the gas utility. In terms of safety, the ability to make authoritative decisions and update response conditions on a second-by-second basis can be the difference between life and death.
- To successfully demonstrate a situational awareness solution, further business process development and targeted user interviews to define the ultimate end users of the

application are imperative. Ultimately, PG&E has developed applications that currently serve their needs. There is potential to increase speed of response in the event of an emergency if the field workers were trained and had the appropriate application available to respond. Future work in this area would require direct solicitation of gas utility's requirements to ensure the solution would be a fit.

- The most beneficial element of the situational awareness tool identified during the project was its ability to pull together data from various sources in real-time. In general, utilities do not have wide access to such information. Access to real-time spatial data is provided only to their gas operations control center. Over time, utilities are expected to make data more available as employees become more advanced in using mobile applications and data sources are validated.

Recommendations to Improve the Tool

- Develop a native application to improve its usefulness and capabilities. A native application uses the software development kit provided by the operating system manufacturer to take advantage of the hardware device's capabilities. This can improve the user's experience and provide direct access to specific features of the operating system if needed. Native application development, however requires more development time, and particular development capabilities and hardware. In addition, a native application for iOS must go through Apple's approval process.
- Minimize login steps. This would require integrating the complete solution with the utility's IT infrastructure and would require multiple security compliance audits and a significant time investment from the utility.
- Allow users to login using their LAN IDs. This would require the utility to host all data for the application and provide rights to allow users to sign-in using their enterprise LAN IDs. A significant effort from the utility would be required to enable this functionality.
- Allow users access to an offline version of the tool if there is no cellular coverage.

The first three recommendations are related and can potentially be addressed in a native tool application. The fourth recommendation is currently not feasible as the out-of-the-box Esri solution does not have this functionality. Offline capabilities would only be available through a custom developed application.

Potential Future Additions to the Tool

As GTI worked with PG&E to develop a situational awareness solution that would provide benefits to PG&E, a number of related topics were discussed. GTI provided the following list of potential ideas to improve the situational awareness tool:

- Real Time Workforce Management for use in Emergency Situations: Monitoring locations of crews, equipment, and skill sets needed to respond to an emergency. Based on criteria reported in real-time about the emergency, specific personnel, equipment, and skill sets could be notified and sent to the emergency directly via notifications (email or text). Additionally, spatial analysis could play a part in getting the proper people to the incident quicker based on their proximity to the emergency.

- Use of Crowdsourcing Information to Aid in Emergency Response: Use real time data feeds from social media outlets like Twitter to collect data about emergency situations. Key words would be scrubbed and used to provide insight about the incident.
- Real Time Predictive Information based on historical incidents: Real time information and suggestions on the behavior of the emergency situation are provided based on knowledge from previous incidents. Emergency responders would be notified of the incident with additional information provided by predictive analytics.
- Waze Connected Citizen Program Integration: Leverage the Waze (social navigation application) functionality to enable bidirectional communication of incidents occurring within PG&E service territory. The Waze product can integrate with Esri's GeoEvent Server to provide real-time updates of traffic and incidents from the Waze platform.
- Spatial Risk Analysis of Previous Dig-In Related Incidents: Use spatial analysis and mapping tools to review data related to high-profile incidents that have occurred within the PG&E service territory. This analysis would look for spatial patterns in the information associated with the gas system and the events leading up to an incident. This data could potentially be used to be a pre-identification of future incidents.
- Dig-In Simulation and Use Case: Based on discussions between GTI and PG&E, an idea was proposed based on the existing situational awareness tool to simulate a dig-in on the gas system and model the emergency response and outages of the gas and electric systems.
- Develop a Native Application: Develop a native application to increase responsiveness, especially in areas of slow or uneven Wi-Fi and cellular connections.

Future Research Recommendations

The research team offers the following recommendations for future research in this area:

- Develop solutions to continue eliminating the need for manual records.
- Improve the accuracy of underground asset mapping. As per PG&E, achieving an accuracy of +/- 6 inches 95 percent of the time for the latitude/longitude would be sufficient and consistent with the distribution pipe sizes and fitting assets for higher accurate GIS maps. However, for further enhancements, improving the accuracy of the z-axis and digesting the GNSS data into GIS that maintain both cartographically appealing maps as well as high-accuracy GNSS location data will reap the full benefits of the HAM technology.
- Improve consistency of mapping accuracy between users and equipment. There was considerable variation in HAM accuracies between different users and asset types. Future research could focus on accurately identifying and addressing the causes for these variations.

- Develop a native application for situational awareness that allows integration of asset mapping data, static data (that is schools and hospitals) and dynamic data updated in real time (that is, excavation equipment movement), and provides dynamic displays to inform users of current conditions and activities
- Develop a tool to provide real time predictive information based on historical incidents. The tool would provide real time information and suggestions on the behavior of the emergency situation based on knowledge from previous incidents. The tool can also notify emergency responders about the incident with additional information provided by predictive analytics.
- Fund the development of technologies that leverage high-accuracy maps to fully realize the value for damage prevention and emergency response. For example, development of a robust as-built tool to generate high-accuracy maps and data records, with automated dimensions used to generate as-built reports in digital format could provide reports to be archived and used for review in planning, shared with crews without access to the LocusView Solutions tools, and used by locators to improve the accuracy.

LIST OF ACRONYMS

Term	Definition
ASTM	American Society for Testing and Materials
DOT	Department of Transportation
EEN	Excavation Encroachment Notification
Esri	Environmental Systems Resources Institute
EFV	Excess Flow Valve
GIS	Geographical Information System. Designed to capture, store, manipulate, analyze, manage, and present all types of geographical data.
GPS	Global Positioning Systems. A system of satellites, computers, and receivers that can determine the latitude and longitude of a receiver on Earth by calculating the time difference for signals from different satellites to reach the receiver.
GTI	Gas Technology Institute
HAM	High-accuracy Mapping
iOS	Apple's Operating System for Mobile Devices
LANID	Local Area Network Identification
LVS	LocusView Solutions
OQ	Operator Qualifications
OTD	Operations Technology Development. A member-controlled partnership of natural gas distribution companies formed to develop, test, and implement new technologies.
PG&E	Pacific Gas and Electric Company
PHMSA	Pipeline and Hazardous Materials Safety Administration
RD&D	Research Development and Demonstration
RTK	Real Time Kinetics
SAW	Situational Awareness Widget
SQL	Microsoft Structured Query Language
TAMI	Tactical Analysis Mapping Integration
UAT	User Acceptance Testing

APPENDIX A:
High-Accuracy Mapping Job Aid 02

LocusMap Mapping Module Job Aide

LOCUSVIEW

Logging In

1. Unlock the tablet with passcode **1234**
2. Tap the "LocusMap" icon on the home screen
3. Use the provided username and password to log in

   Username: **lanid** (Your LAN ID)
   *username is **not** case sensitive!*

   Password: **lanidlvs!**
   *password **IS** case sensitive!*

NOTE: RTK is now turned on and connected automatically

General Workflow

1. On the **Home** screen:
2. Tap on the **Project** field to create or select a **Project**
   a. Tap the 'Plus' button if you need to enter a **Project** number and set the default system type to **Main** or **Service**

      ***System Type** can be changed later on the **Collect Data** screen*

      *The **Generate** button is only to be used for projects that do not have a **Project** number assigned, such as emergency work*

   b. Tap your new or existing project
3. Tap the Mapping module on the **Home** screen

   On the Collect Data screen, you can change the System Type by tapping Change at the bottom right of the screen
4. On the **Collect Data** screen, scan the ASTM Barcode located on the Asset

   If prompted to scan a joint barcode, select 'continue without joint'
   This capability will not be tested during this pilot
5. Use the button to take a GPS point
   Note: At least two points are required for pipe
6. Use the camera icon in the **Actions** toolbar to attach a picture to the collected point
   Attach at least one picture per bell Hole
7. Save the collected asset with the 'Check' button

ASTM Barcode Availability or Accessibility

In cases where the asset does not have an ASTM Barcode available or accessible, follow the workflows below. *These are in order of preference.*

1. **Materials List**
   Select from a list of predefined PG&E materials
   Filtered by size and ordered alphabetically by asset type
2. **Manual Entry**
   Manually enter asset information
   Asterisks(*) indicate mandatory fields
3. **Type ASTM Code**
   Type in the 16-digit ASTM Barcode characters
   Case sensitive!

Mapping Existing Assets

When you are in the field and need to collect data on exposed existing assets, you'll use **Manual Entry** to select **Existing Fitting** or **Existing Pipe**

1. Tap on **Manual Entry** to choose **Existing Fitting** or **Existing Pipe**
2. Tap on each field and enter information for asset type, connection type and material to describe the existing asset
3. Use the **Deactivated** checkbox to record if you deactivated the asset
4. Enter detailed notes in the **Comments** field and tap the checkmark
5. Map the asset as described in the **General Workflow** section above

Submitting a Project

When you tap the **'Check'** button on the mapping screen after collecting the last asset you will be returned to the **Collect Data** screen

1. Tap the clipboard icon in the top right corner to view the collected assets for the current project
2. At the bottom of the screen, tap **'Submit Project'** then tap **OK**
   *You can re-open a submitted project by adding a new project with the identical Project Number in the Project field on the **Home** screen*

Best Practices

1. **Start at the Service Tee to ensure best accuracy**
   Start collecting assets at the service tee where your GPS fix will be most accurate and move towards the least accurate location, the riser.
2. **Keep the pole upright**
   When walking between locations keep the pole upright to ensure the antenna always has access to multiple satellites.
3. **Allow time for GPS to warm up**
   The GPS receiver takes 5-10 minutes to connect and get a fix
   Make sure the antenna has clear view of the sky in the warmup location
4. **Make sure cables between GPS and antenna are tight**
   Even slightly loose cables can affect accuracy
5. **Use the level**
   The pole has a level to ensure the highest accuracy is being obtained
6. **Captured all exposed existing assets along with new plastic assets.**
7. **The GPS source should read Fixed RTK**
   There is a GPS Status Bar at the top of the mapping screen that shows your GPS source and number of satellites at the left, and your current accuracy at the right; Fixed RTK is the highest level of GPS accuracy, followed by Float RTK and least accurate is DGPS

8. **Accuracy should be within six inches**
   The goal for the project is to collect the majority of assets with an accuracy of six inches or better and an audible alarm will sound on the tablet whenever accuracy is greater than six inches
   If the accuracy is greater than six inches keep the pole and antenna upright with a clear view of the sky and wait up to two minutes for the GPS fix to improve; if accuracy within six inches is not achieved, you should still collect assets
9. **Document all visible assets (exposed or new pipe/fittings) with at least one picture of the entire open hole**
   *After collecting an asset, tap the camera icon in the **Actions** toolbar to take and attach a picture to the asset record*
   Take at least one picture per open bell hole to show all visible assets. If not on the mapping screen, tap the clipboard icon in the upper right to go to the review screens; tap the desired asset then tap the Camera icon in the upper right
10. **For Service work, first collect all Fittings then return to the Service Tee and collect the Pipe**
    this order will ensure the greatest accuracy as well as the simplest workflow

APPENDIX B:
Situational Awareness Job Aid

The following is the situational awareness Web application Job Aid:

Situational Awareness Web Application Job Aid

Logging In

1. Unlock the tablet
   a. All tablets have the same pin code to unlock the tablet: *XXXX*
2. Open the "Safari" app on the home screen
3. Click on the Bookmarks Tab at the bottom of the Safari app
4. Select the Situational Awareness_WAB_App bookmark
5. Use the provided username and password to log in (you may be asked to log in more than once, if so, just use the same credentials a second time) .
   a. Username: XXXXXXXX
   b. Password: XXXXXX

Tools and Functions

1. On the main Situational Awareness Web Application screen test the following:
   i. Use the mouse to Zoom In/Zoom Out on the map. When the user zooms into the city level Schools, Hospitals, Fire Stations, Police Stations and Transmission Lines will turn on. Transmission lines will change to unique colors based their diameter when zoomed in closer to street level
   ii. Click on any feature (school, transmission line, etc.) in the map, a pop up box should appear with details about that layer

2. In the upper left corner of the application there are four tools and four widgets (widgets will be covered in the next section of this document):

   2.1. ***The Plus/Minus +/- Tool:*** This tool is used for zooming in and out
   2.2. ***The Home Button Tool:*** This tool will set the map back to the default extent
   2.3. ***The Location Tool:*** This will take the map to your current location
   2.4. ***The Esri World Geocoder Tool:*** This tool allows the user to search for an address on the map

3. In the upper right corner there are two tools:

May 23, 2018 Situational Awareness Web Application Job Aid gti

3.1. ***The Legend Tool:*** This tool displays the layers that are turned on in the map. As you zoom in on the map more layers will be displayed in the legend

3.2. ***The Layer List Tool:*** This tool list all of the layers that are contained in the map. Layers that are grayed out are not shown on the map. You can check and uncheck the box for each layer to turn it on or off as well as click on the ellipsis button (...) to the right of each layer to get a list of other options as seen below.

Widgets

1. In the upper right hand corner of the web application there are also four widgets:

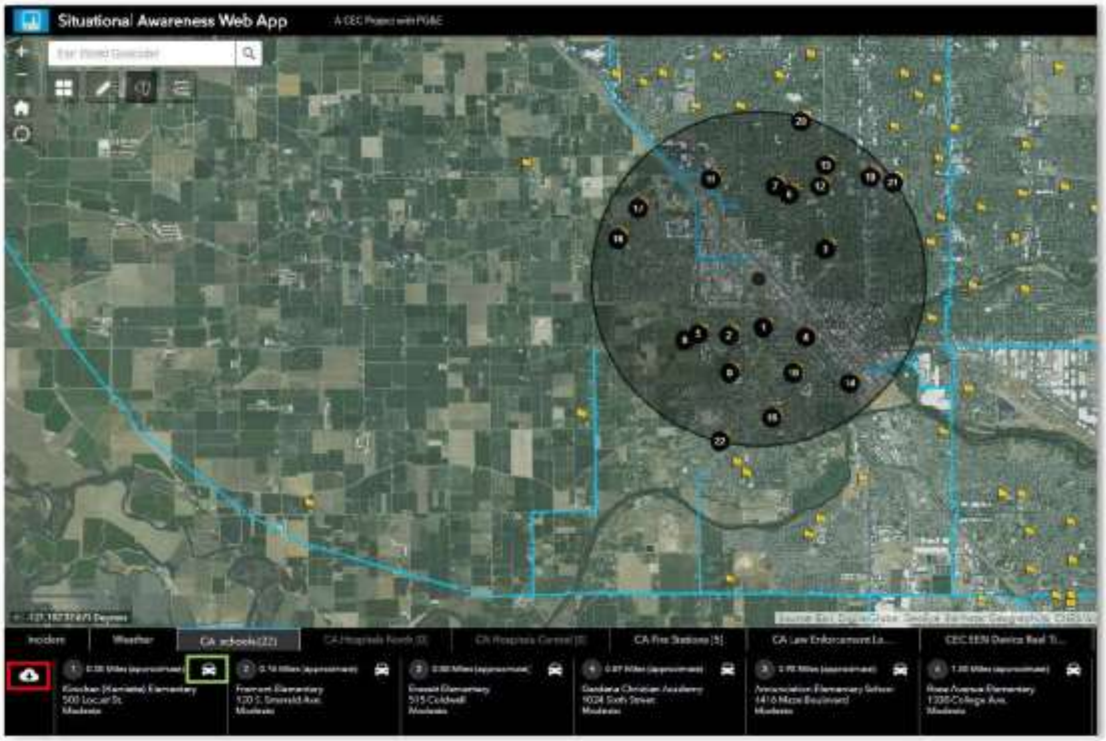
a. ***The Basemap Gallery Widget:*** This widget allows the user to switch the underlying base map being displayed in the application

b. ***The Measurement Widget:*** This widget allows the user to click on two separate points on the map to measure the distance or select multiple points to construct a polygon and receive an area calculation

c. ***The Situation Awareness Widget:*** This widget allows the user to do analysis and provide outputs from an incident location on the map. General "How To" steps are listed below:

   i. Zoom into an area of interest
   ii. Click on the Situation Awareness Widget
   iii. Select a Buffer Distance
   iv. Select to draw a Point, Line or Polygon on the map

v. Draw that feature on the map - at this time the buffer will be created and multiple layers that intersect this buffer will retrieve a count and list. See image below where 22 schools were found:



vi. In the bottom left corner of the results window click on the download option (shown in the red square in the image above). This will export the result of that specific category (i.e. schools) to a CSV file

vii. Next to each result the user can click on the small car (shown in the green square in the image above) to get driving directions from that feature (i.e. schools) to the incident location

viii. To rerun the tool the user just needs to click on the "Incident Tab" and then click on the "Start Over" button

d. ***The Directions Widget:*** This widget allows the user to get driving directions from any two locations on the map. General "How To" steps are listed below:

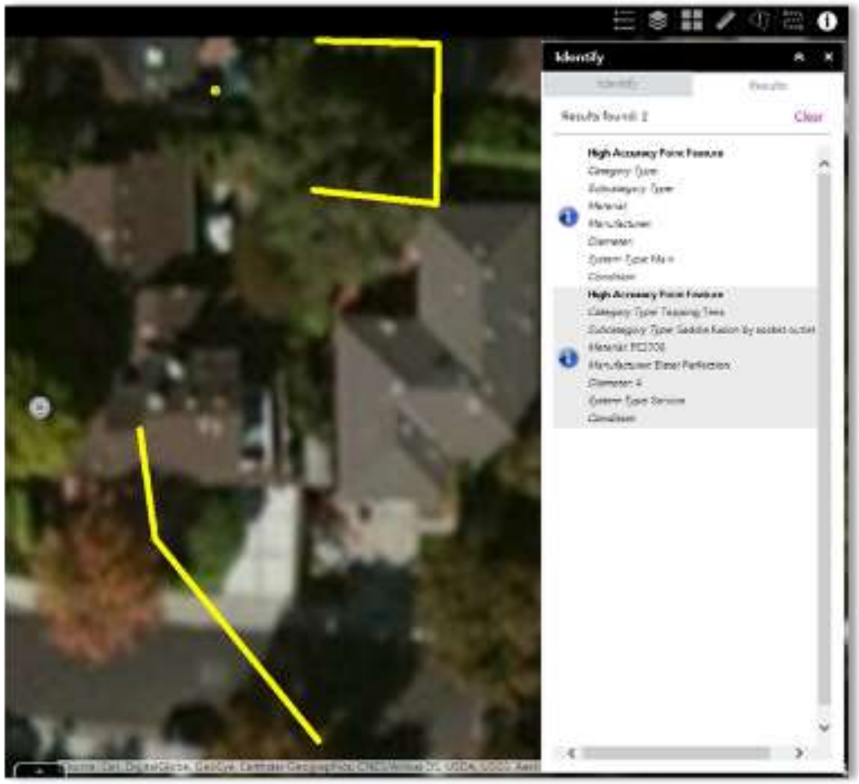
i. Click on the Directions Widget

ii. Type in a starting address and ending address then click "GET DIRECTIONS"

iii. Advanced options include the following:

- Switching the mode of travel from "Driving Time" to something else (i.e. Rural Driving Time)
- Selecting to "LEAVE NOW" or "DEPART AT" for a specific date and time
- Add stops by clicking on the map
- Add barriers for re-routing the directions (i.e. change directions to avoid a known road closure)

e. The Identify Widget: This widget allows the user to control which features on the map are identified. This is helpful in areas where there is a lot of data and the user is only interested in certain information. The figure below depicts this tool in more detail.



APPENDIX C:
Situational Awareness User Guide

The following is the situational awareness Web application user guide.

CEC Situational Awareness Web App User Guide

Access

Access web app via the URL below or through the bookmarks option in the Safari app on the tablet:
https://xxx.xxxxxxxxx.zzz/SituationalAwareness_WAB_App/
Log In to Web App:
Username: XXXXXX   First Password: XXXXX

*NOTE: You may be asked to log in more than once, if so, just use the same credentials a second time

Tools

Use the Zoom In/Zoom Out, Esri World GeoCoder, and Location Tools to find a location of interest or set the map back to the default extent with the Home button

Tools

Use the Legend tool to see what symbols on the map stand for and use the Layer List Tool to turn on and off operational layers in the map

Widgets

1.) Use the Basemap Widget to change the underlying map in the application
2.) Use the Measurement Widget to measure distances or area on the map
3.) Use the Situation Awareness Widget to do analysis about features within the proximity of an incident
4.) Use the Directions Widget to get directions between two places on the map

For more information on how to use the web application please refer to the CEC Situational Awareness Web Application Job Aid Document

gti

APPENDIX D:
Overview of Situational Awareness

The following document is an overview of situational awareness:

Introduction

Through the use of new or previously created data, one can publish, stream or collect important information that is vital to making decisions in a time of urgency. No longer should someone have to wait to get data into the hands of those who need it most. Via current technologies created and maintained by Esri or through means of open source contributors, data is now stitched together in one centralized platform accessible to all and is much easier to configure.

Spatial data, whether it be static or dynamic, becomes the catalyst for relationships that help make decisions immediately. Locations of features and their relevance to other nearby features exposes answers to the questions asked. With all of this in mind GTI plans to demonstrate this functionality via a centralized situational awareness platform utilizing the data, technologies and methodologies listed below.

Data Considerations for Static and Streaming

- *Utility Data* - Gas, Water, Sewer and Electric (Static Web Map Layer)
- *Road Closures* (Active Streaming Data Layer from Field Collection)
- *Nearest Hospitals* (Static Web Map Layer)
- *Nearest Ambulances* (Active Streaming Layer from Devices in Trucks)
- *Fire Stations* (Static Web Map Layer)
- *Schools* (Static Web Map Layer)
- *Nearest Police* (Active Streaming Layer from Devices in Trucks)
- *Current and Future Weather Forecast* (Active Streaming Layer from Weather Service)
- *Water Leaks* (Active Streaming Data Layer from Field Collection)
- *Gas Leaks* (Active Streaming Data Layer from Field Collection)
- *Methane Levels* (Active Streaming Data Layer from Field Collection or Sensors)
- *Residences within Proximity of Disaster* (Static Web Map Layer)
- *Data from Neighboring Counties that is Interactive* (Active Streaming Layer from Shared Services)
- *Notifications based on Area* – Could be Text, Automated Phone Messages (Based on Events from Other Layers or just Standard Notifications)
- *Public Data Feeds from Customized App or 311 Systems* (Active Streaming Data Layer from Field Collection)

Technologies

- *ArcGIS for Emergency Management* – Optional Extension
- *ESRI Disaster Response Program* - Consult with ESRI to help build platform
- *ESRI Operations Dashboard* – Streaming data and analytics for command center operations

Events and Notifications-

- Using the GeoEvent Processor Extension for ArcGIS Server, models can be created to poll for streaming data, defining geofence boundaries and sending alerts (text messages, emails, etc.) based on interactions of live and static data
- Inputs from other systems and sensors can be added to the models as an option to scale out for additional data sources pertinent to situational awareness programs
- Outputs from the GeoEvent Processor can be created to feed data and alerts back to other systems being used within the situational awareness program

Conclusion

Situational Awareness can take many forms and is dependent on the business process and workflows that exist within an organization. In modern situational awareness applications, there is always a basis in spatial data and implementation of an enterprise-wide GIS to facilitate the collection, storage and management of real-time events occurring in the field. Events that can occur that can benefit from situational awareness are not always emergencies. Situational awareness also includes providing pertinent information to an employee that might not typically be in the field and wants to understand the current operations being conducted within the Gas Utility service territory. Situational awareness applications can be built to satisfy both use cases and ultimately provide tools and capabilities to leverage spatial data and decision-making workflows.

APPENDIX E:
Workflow Diagram for Situational Awareness Web Application

This workflow diagram depicts the process used to interact with the Situational Awareness Web Application.