Global Positioning System Excavation Encroachment Notification System Implementation
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PREFACE

The California Energy Commission Energy Research and Development Division supports public interest energy research and development that will help improve the quality of life in California by bringing environmentally safe, affordable, and reliable energy services and products to the marketplace.

The Energy Research and Development Division conducts public interest research, development, and demonstration (RD&D) projects to benefit California.

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Energy Research and Development Division funding efforts are focused on the following RD&D program areas:

- Buildings End-Use Energy Efficiency
- Energy Innovations Small Grants
- Energy-Related Environmental Research
- Energy Technology Systems Integration
- Environmentally Preferred Advanced Generation
- Industrial/Agricultural/Water End-Use Energy Efficiency
- Renewable Energy Technologies
- Transportation

GPS Excavation Encroachment Notification System (GPS EENS) Implementation – Final Report is the final report for the GPS Excavation Encroachment Notification System Implementation project (grant number PIR-15-015) conducted by Gas Technology Institute (GTI). The information from this project contributes to Energy Research and Development Division’s Energy Technology Systems Integration program area.

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

The Global Positioning System (GPS) Excavation Encroachment Notification System Implementation project focused on developing and implementing technology to enhance situational awareness of excavators and to significantly reduce the risk of excavation damage to utilities’ infrastructure.

A GPS unit, in conjunction with communications and motion sensors, were assembled in one device and installed on excavators to provide utility operators with real-time accurate locations and operational status of excavating equipment. A dashboard interface provided the utilities with the excavator status and location in relation to their pipeline facilities.

This project:

- Installed 150 Excavation Encroachment Notification units on excavators and agricultural equipment within the utility’s service territories and provided the system architecture to support it. The utility communication protocols were developed to accommodate various levels of enterprise scaling and sustainability.

- Configured and deployed an operations dashboard. The dashboard displays excavator’s location, state of operation, right-of-way boundaries of pipeline infrastructure, and provided alerts in real-time in relation to the utility pipeline assets.

- Used the system architecture to enhance emergency response situational awareness by providing a platform for accurate incident location, targeted alerts, communications, and near real-time access to geographical information system asset maps.

The benefit of using the technology has already been initiated by installing about 150 units in the utility’s own equipment, as well as in participating contractors’ excavators. Such deployment targeted 12 percent of the non-significant incidents in California which are caused by first- and second-party excavators and cost about $1,564,500 annually. Furthermore, deploying the technology to third-party contractors would result in further significant recognition of the benefits and impact on excavation safety.

**Keywords**: Natural gas, transmission, distribution, gas pipelines, excavation, third-party damage, encroachment, GIS, GPS, ROW, safety, regulations, implementation

Please use the following citation for this report:

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EXECUTIVE SUMMARY

Introduction

Accidental damage to natural gas pipelines caused by digging, grading, trenching, and boring is one of the main challenges to safe pipeline operations. The U.S. Department of Transportation Pipeline and Hazardous Materials Safety Administration reported that excavation damage is the root cause of about 26 percent of gas transmission and distribution pipeline serious incidents (Figure 1). In California between 2010-2016, this excavation damage resulted in ‘significant incidents’ in gas transmission and distribution lines with average annual losses of $2,178,700 and 66,760 thousand cubic feet of gas ignition\(^1\). Additionally, according to Common Ground Alliance, there are about 5,600 other “non-significant, non-fatal, non-injury” excavation incidents each year. These incidents resulted in estimated cost of $30,604,960 in 2016. About 43 percent of these incidents were caused by backhoes, trenchers, and other excavators resulting in an estimated cost of more than $13 million\(^2\).

The California Public Utilities Commission’s 2016 Annual Report stated that California experienced numerous natural gas incidents; about 50 percent of these were caused by third-party excavation damages. This often results from failure to follow one-call notification practices before digging, lack of accurate facility locate markings, or failure to follow standard procedures for excavation around utility lines.

Figure 1: Transmission and Distribution Lines Serious Incidents by Cause (2005-2016)


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\(^2\) Common Ground Alliance (CGA) http://commongroundalliance.com/dirt-2016-interactive-report
Project Purpose

To help address excavation damage in the field, this project designed, developed, and tested a Global Positioning System (GPS) Excavation Encroachment Notification System. The project objectives included:

- Improving public safety and natural gas system integrity by mitigating excavation damage to utilities’ infrastructure.
- Improving public safety by providing enhanced situational awareness of excavators operating in utilities’ service territories, including automated preemptive alerts to the excavators’ operators and utility personnel.
- Improving emergency response to pipeline incidents by providing real-time Geographical Information System (GIS) asset maps, accurate damage locations, and targeted communications to utilities’ first responders and local law enforcement.

The GPS Excavation Encroachment Notification technology used hardware components installed on an excavator and a software system running on a utility’s GIS network. The hardware unit (Figure 2 [a]) incorporated a GPS system, cellular data connectivity, motion sensors, and other sensors related to data collection and communication protocols.

The utility monitoring dashboard (Figure 2 [b]) used a combination of Environmental Systems Research Institute products, including the Operations Dashboard and Geo-Event Processor. The dashboard also used custom-developed algorithms to determine an excavator’s behavior and the state of operation such as moving, idling, and digging. This dashboard interface provided the utilities with the excavator status and location in relation to their pipeline facilities.

Figure 2: GPS EEN Device on Excavator and Utility Monitoring Dashboard

Source: Gas Technology Institute

Project Results

Several prototypes of the hardware were developed and installed at utility sites. Applying this technology provided a real time interface to the utility operators, allowing for monitoring the excavation equipment in the utility territory while making informed decisions on monitoring and prioritizing response activities.
The research team:

- Delivered 150 GPS Excavation Encroachment Notification devices to Pacific Gas and Electric Company (PG&E) and Southern California Gas Company (SoCal Gas) to install on their own and contractors’ excavation equipment. The original development plan was to work only with PG&E in the project. When the device was built and demonstrated to SoCal, SoCal engineers were interested in trying the units and 20 devices were sent to them.

- Built the system architecture and configured the components to process data from the GPS Excavation Encroachment Notification devices on the Amazon Web Services Platform using Environmental Systems Research Institute GIS Software. The data included a map of the utility pipeline system, a list of active excavators, and a display of excavators’ locations on the map. Historical graphs displayed the last 24-hours of excavators’ activities and a list of all registered devices. The list identified the excavators’ attributes such as the type, owner, and photos of the equipment.

- Configured the Environmental Systems Research Institute “Operations Dashboard” and machine learning algorithm to identify and alert users. The utilities dashboard provides historical and statistical data of the equipment activities. These data identify areas with high potential of encroachment, activities of specific equipment, and digging locations in the pipeline zones.

- Monitored excavations to enhance the algorithm to identify the digging activities and provide real-time alerts. Validating the activities recognition algorithm was performed by matching actual field observations against the excavators predicted activities of idle, digging, and driving. The accuracy of correctly predicting the idle, digging, and driving activities were about 87 percent, 80 percent, and 85 percent, respectively.

Project Benefits

Implementing the GPS Excavation Encroachment Notification technology would improve public safety and operational efficiency. The project successfully developed and demonstrated a technology and approach to enhance locating and warning systems of excavators operating near or on utility infrastructure and significantly reduce the risk of pipeline excavation damage. The integrated system provides real-time awareness of the excavator location and operating status relative to right-of-way boundaries.

The benefit of using the technology has already been initiated by installing about 150 units in utility-owned equipment, as well as in participating contractors’ excavators. Such use targets 12 percent of the non-significant incidents in California which are caused by first- and second-party excavators. These non-significant incidents cost about $1,564,500 annually.

Further use of the technology by third-party contractors, in areas where gas pipeline systems exist, is anticipated in the following few years through the commercialization of the technology. This will target a 43 percent reduction of non-significant excavation incidents which are caused by excavators, backhoes, and trenchers. GTI developed a commercialization strategy to bring
the technology to market. GTI has discussed a potential commercialization path with Elecsys Corporation, a leading provider of machine-to-machine (M2M) technology solutions and custom industrial electronics. GTI and PG&E had in-depth discussions and hosted webinar demonstrations with Caterpillar-Trimble and other industries to commercialize this technology, develop potential business models, and discuss partnership opportunities. Moreover, GTI, with PG&E and SoCal Gas plans to create an industry-led working group to lay the foundation of a commercial test market. More savings can be achieved if telecommunication, electrical, water, and agriculture industries recognize and install the excavation safety technology.
CHAPTER 1:
Introduction

1.1 Project Objectives

Implementing the GPS Excavation Encroachment Notification (GPS EEN) system will reduce excavation damage and provide enhanced awareness of excavators operating near or above utility infrastructures. This project:

- Developed an excavation monitoring device with GPS, which overlays the utility’s GIS map services, pipeline boundaries, and custom geo-fence boundaries around pipelines ROW.
- Provided real-time indications of the activities of the geospatially-located excavators.
- Provided instant alerts in the form of sound and light signals in the device, plus graphical and text message alerts to the utility’s operators. These messages are custom-set when an excavator enters a pipeline boundary or when an unauthorized digging activity is occurring next to a utility’s infrastructure.
- Generated additional alerts for first response situational awareness, when an emergency situation is identified. The GIS mapping system can be made available through the mobile operations dashboard for real-time utility response in the field.

The benefits were quantified by a measurable decrease in excavation damage to utilities pipelines. Emergency response and mitigation time was also reduced by providing site location, GIS asset maps, and alerts in near real-time.

This report is the final report of the project and presents the development, installation, and deployment of the GPS EEN devices and operation dashboards. The EEN devices were installed on excavators in the Pacific Gas and Electric (PG&E) and Southern California Gas Company (SoCal Gas) gas service territories, as well as the system architecture and dashboards to support them. These units were installed on traditional backhoes and excavators and agricultural equipment.

The report also evaluated the benefits of the technology in reducing excavation damages and increasing safety.

1.2 Report Structure

The project objectives were addressed in these chapters:

- Chapter 2: System Components and Development. This chapter details the development of the GPS EEN hardware and operations dashboard.
- Chapter 3: Installation and Data Management. This chapter addresses the data management and calibration algorithm of the equipment for encroachment detection and notification.
- Chapter 4: System Deployment. This chapter presents the installation and monitoring of the hardware at the utilities territories.
- Chapter 5: Evaluation of Project Benefits and Cost Analysis.
- Chapter 6: Technology Transfer Plan. This chapter addresses the development of situational awareness approach and the activities performed to commercialize the system.
CHAPTER 2: System Components and Development

2.1 Hardware Technical Approach

The GPS Excavation Encroachment Notification (GPS EEN) hardware unit used an ‘Agile’ development procedure consisting of iterative and incremental development of the hardware prototypes. Each prototype was developed to provide full operational capability, with the first one containing only the basic requirements. Testing each prototype identified new features for future prototypes. Figure 3 shows this procedure.

![Figure 3: Layout of the Device Incremental Development Procedure](Source: Gas Technology Institute)

The Agile procedure identified development gaps and simplified troubleshooting of various issues that would arise at each level. It also provided flexibility and speed in responding to the product changes. The process required collaboration between the development team and the utilities involved in evaluating the product. The communication loop between the design, development, and testing was repeated for the multiple development stages (Figure 4). Weekly conference meetings were held throughout this task with PG&E to identify their needs and coordinate with the dedicated project team.

Several versions of the GPS EEN devices were developed and installed at PG&E throughout this task. Table 1 shows the features of these versions. Prototypes 1-A and 1-B had similar features and were developed and tested at GTI’s facility for basic evaluation.

Five units of Prototype 2 were built for initial field evaluation. After that, 30 units of Prototype 3 were built, which provided 2-way signal transfer between the Environmental Systems Research Institute (Esri) GeoEvent Server and the excavator. Prototype 4 included 60 units which were deployed at PG&E with advanced warning signal functionality, while 60 units of prototype 5 were configured to have a software update capability, allowing for variable recording rate and included excavation activity recognition algorithm. A total of 150 devices were shipped to the
utilities as planned. More units of the new version of the prototype were built to replace some field units that had older versions or did not function properly (about 15 replaced units). The overall units in service, after these replacements, were 150 (PG&E: 130 and SoCal: 20)

Figure 4: Communication Loop for the Prototype Development

![Communication Loop Diagram]

Source: Gas Technology Institute

Table 1: Design Features of the GPS EEN Prototypes

<table>
<thead>
<tr>
<th>Features</th>
<th>Prototype Version</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>1-A</td>
</tr>
<tr>
<td>Hardware</td>
<td></td>
</tr>
<tr>
<td>Board Type: - Development Board</td>
<td>X</td>
</tr>
<tr>
<td>- Commercial Board</td>
<td>X</td>
</tr>
<tr>
<td>Battery Backup</td>
<td></td>
</tr>
<tr>
<td>Hard-wired to equipment</td>
<td></td>
</tr>
<tr>
<td>Antenna: - Separate</td>
<td>X</td>
</tr>
<tr>
<td>- Integrated</td>
<td></td>
</tr>
<tr>
<td>- Integrated, oriented</td>
<td></td>
</tr>
<tr>
<td>Display Screen [Modified in each prototype]</td>
<td>X</td>
</tr>
<tr>
<td>Buttons Input</td>
<td>X</td>
</tr>
<tr>
<td>Light Signals [Improved in each prototype]</td>
<td>X</td>
</tr>
<tr>
<td>Sound Signals [Improved in each prototype]</td>
<td>X</td>
</tr>
<tr>
<td>Water Proof Case</td>
<td>X</td>
</tr>
<tr>
<td>Software</td>
<td></td>
</tr>
<tr>
<td>1-way Communication signal</td>
<td>X</td>
</tr>
<tr>
<td>2-way signal [Operator feedback]</td>
<td></td>
</tr>
<tr>
<td>Activities Identification Algorithm</td>
<td>X</td>
</tr>
<tr>
<td>Data stream rate: - 5 sec</td>
<td>X</td>
</tr>
<tr>
<td>- Variable, 1-hour at idle</td>
<td></td>
</tr>
</tbody>
</table>
2.2 Prototypes Components and Features

2.2.1 Prototype-1

Two versions of this prototype were built. Prototype 1-A was built at Gas Technology Institute (GTI) and consisted of the GPS unit, cellular unit and antenna, motion sensors, and power board (Figure 5). The unit had an outside GPS antenna. Prototype 1-B was built by a vendor and included an internal GPS antenna and a battery backup. Figure 6 shows the components of Prototype 1-B. Both versions of the prototype were tested at the GTI testing facility to evaluate the GPS and cellular signals as well as the performance of the motion sensors.

Figure 5: View of Prototype 1-A of the Device Hardware

Source: Gas Technology Institute
2.2.2 Prototype-2

Prototype 2 was an upgrade of Prototype 1-B and consisted of adding a display screen and a ‘DIG’ button (Figure 7). The units also excluded the battery backup option of the earlier prototype. The installation and data transfer of Prototype 2 were evaluated in utility excavation equipment.

Along with the construction of this prototype, the background architecture was developed and included the Esri ArcGIS software and Amazon Web Server Instances to handle the incoming data from the devices and store them in the backend databases.
Additional setup also included creating a web mapping service on ArcGIS for live data streaming and a desktop dashboard. When the data management setup was completed, GTI monitored the data in a field test to ensure that it was properly posted with live feeds to the dashboard. Adjustments were made to ensure the stability of the system.

2.2.3 Prototype-3

Thirty units of Prototype 3 were installed and tested on various construction equipment (Figure 8). The main design features of this prototype included:

- Integrated antenna, oriented at the top of the unit for optimal signal strength
- Multicolor display for power, satellite and GPS signals, and warning messages
- Two-way communication, sending data to the server at a rate of five seconds
- An alarm signal is triggered when a message is sent from the server. The alarm signal was initially integrated inside the box (left) and was later enhanced with a larger external buzzer (right).
- Two-Button input to mute the alarm signal and to send a signal to the server that the equipment is digging.

Figure 8: View of Prototype 3 of the Device Hardware

Source: Gas Technology Institute

2.2.4 Prototypes 4 and 5

Prototype 4 was an update of Prototype 3 design features, with various modifications to improve its resiliency, alarm signal, and connection to the equipment power supply. These modifications provided brighter display and a louder sounding alarm than the earlier versions. For Prototype 4, the alarm module was placed at the front panel and the power supply was modified to accommodate variable input from 12 to 24 VDC.

Prototype 5 had similar hardware features to Prototype 4, with improvements in the device software to provide:
Motion detection algorithm to detect the equipment’s digging, driving, and idle activities. The device triggers a warning signal if the operator is digging inside the pipeline’s designated areas.

Updated data stream rate to send data to the server every five seconds when the equipment is operating and then once every hour when the equipment is idle. This feature optimizes the size of the data transfer to the server.

Modify the warning signal to include separate warning light and alarm sound based on the utility’s setup.

Sixty units were produced from each of these prototypes for installation on excavation equipment at utilities sites. Figure 9 shows prototype 5 of the device and Table 2 shows the main design features of the prototype.

**Figure 9: View of Prototype 5 of the Device Hardware**

Source: Gas Technology Institute
Table 2: Design Features of Prototype 5 Hardware

<table>
<thead>
<tr>
<th>Feature</th>
<th>Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Hardware</strong></td>
<td></td>
</tr>
<tr>
<td>Power supply</td>
<td>12 – 24 VDC from the vehicle</td>
</tr>
<tr>
<td>Power cable</td>
<td>Power cable is hard wired to the device.</td>
</tr>
<tr>
<td>Electronic board</td>
<td>A 100-decibel sound buzzer is installed at front panel.</td>
</tr>
<tr>
<td>Display lights</td>
<td>2 flashing, alternating bright lights.</td>
</tr>
<tr>
<td>Motion sensor</td>
<td>An updated 9DOF sensor connectivity for better performance.</td>
</tr>
<tr>
<td>Label on box</td>
<td>Labels are installed at the top of the device.</td>
</tr>
<tr>
<td><strong>Software</strong></td>
<td></td>
</tr>
<tr>
<td>Alarm signal algorithm</td>
<td>- Algorithm recognizes digging, driving, and idle activities.</td>
</tr>
<tr>
<td></td>
<td>- Alarm signal is muted when the operator presses the silence button.</td>
</tr>
<tr>
<td></td>
<td>- Warning light and sound alarm are set from server side based on the pipelines boundaries setup.</td>
</tr>
<tr>
<td>Software upgrade</td>
<td>Allows for remote software program upgrade.</td>
</tr>
<tr>
<td>Data stream rate</td>
<td>Data to server every five seconds when equipment is active, and every 1-hour when the equipment is idle.</td>
</tr>
<tr>
<td>Display Error messages</td>
<td>Messages are programmed in hardware.</td>
</tr>
<tr>
<td>In case of cellular connection failure</td>
<td>Device re-connects automatically when signal is restored.</td>
</tr>
</tbody>
</table>

Source: Gas Technology Institute

2.3 Operations Dashboard

2.3.1 Utility’s Dashboard

An Esri Operations Dashboard was developed and used by the PG&E pipeline GIS operators to identify the zones where equipment activities may pose risks to the pipeline. Figure 10 shows the dashboard. The dashboard includes a map of the pipeline system of the utility, a list of the active excavators and a display of the excavators’ locations on the map. A historical graph displaying the last 24-hours of excavators’ activities is shown at the bottom of the figure. A detailed list of all registered devices is also displayed. The list identifies the attributes collected during registration, such as the equipment type, any unique characteristics, owner, and photos of the equipment post installation on the construction apparatus.

The dashboard displays various levels of alerts and warning messages set by the operators to identify equipment inside the pipeline boundaries and the ones performing digging operations. The data is linked to several other dashboards for statistical review of the excavation activities.
Figure 10: Operations Dashboard Displaying Map of the Utility Pipeline

Details of the equipment attributes transmitted from the EEN devices are linked to each excavator in the dashboard. The user displays these attributes by clicking on the device in the active excavators list, or on its representative icon on the map. Figure 11 shows a screenshot of a live view in the operations dashboard, showing the device attributes.

2.3.2 Establishing Utilities Geo-Fences

Pipeline boundaries (Geo-fences) were set in the operations dashboard around the utilities pipelines to identify the zones where equipment activities may pose risks to the pipeline. A zone of 50 feet at both sides of the pipelines was set as “geo-fence” boundaries. The designated geo-fences around the pipelines are set by the developers and the pipeline operators to initiate and send warning signals from the server if the equipment performs excavation activities inside these areas.

Figure 12 shows an example of a geo-fence zone set by the user around a utility line right-of-way. The green line shows the geo-fence. The width of the boundary may vary based on risk level of the excavation encroachment and pipeline characteristics. Pipelines in highly populated areas may have wider geo-fences to reduce encroachment risk. Figure 13 shows an example of a dashboard with various sizes of geo-fences around the pipelines.

Source: Gas Technology Institute
Figure 11: Devices Attributes in the Operations Dashboard

Source: Gas Technology Institute
Figure 12: Operations Dashboard Displaying Geo-Fence Added by User

Source: Gas Technology Institute

Figure 13: Operations Dashboard with Geo-Fences for Various Pipe Sizes

Source: Gas Technology Institute
2.3.3 Operations Activities Metrics

Several metrics were developed to monitor the operations of the excavation equipment and to provide statistical analysis of their activities. These metrics were custom-built to monitor system performance and address specific requirements by the utilities and equipment owners.

Figure 14 shows the dashboard developed for PG&E to monitor the performance of the devices’ sensors and to identify the devices with the most activity. The display in the bottom center of Figure 14 shows a chart of the device registration activities since the devices were installed in the field, May 2017. The top middle chart identifies the percentages of “idle” and “digging” activities of all the registered equipment.

![Figure 14: Metrics Dashboard for Devices Performance](image)

Source: Gas Technology Institute

Figure 15 shows a list of the devices with the most and least amount of data points collected monthly and since the deployment. These figures help identify the locations and equipment activities which occur within the pipeline system.

The metrics board in Figure 16 provides equipment information specific to individual owners containing the operations data of their equipment, plus statistical analysis of their activities. The metrics display all active equipment, their registration information, and a map showing their locations.
Figure 15: Metrics Dashboard of Most and Least Active Equipment

Source: Gas Technology Institute

Figure 16: Activities Metrics for Excavation Contractors

Source: Gas Technology Institute
The Operations Dashboard can also be used to track the locations of all excavators active in the field. Figure 17 shows the aggregation of data points where excavation equipment has been working or driving. The red grids in the figure show areas of large data concentration, indicating that excavation equipment has spent more time in these areas.

**Figure 17: Dashboard Showing Areas of Concentration for Excavator Activity**

Source: Gas Technology Institute
CHAPTER 3:
Installation and Data Management

3.1 Introduction

The data collected by the hardware device during construction activities was sampled every five seconds and transferred to the cloud-based server through the cellular device connectivity. The hardware sensors’ data consist of the following:

- The GPS location of the equipment and equipment’s speed
- Equipment’s nine-degree of freedom motion activities; consisting of its acceleration, gyro, and orientation in the x, y, and z directions
- Other status information including device ID, date, time, temperature, and cellular signal condition.

The cloud-based ‘Apache Spark’ system characterizes the activities of the equipment using a machine learning algorithm in real time. The automated system sends alarm notifications to the operators if the equipment activity is evaluated to pose a risk based on the following criteria:

- The excavator’s location is determined to be inside the pipeline’s geo-fence
- The excavator’s speed is less than four miles per hour. This criterion is set based on field observations to reduce false alarms when the equipment is solely driving inside, or crossing, the geo-fences with no excavation activities
- The activity recognition algorithm of the motion sensors indicates excavation work.

Figure 18 shows a layout of the data stream transferred from the EEN device to the cloud server. The figure also shows an example of the data format transferred every five seconds.

Figure 18: Example of the Data Transferred from the GPS EEN Device

<table>
<thead>
<tr>
<th>Geospatial information</th>
<th>Motion information</th>
</tr>
</thead>
<tbody>
<tr>
<td>Latitude</td>
<td>Speed</td>
</tr>
<tr>
<td>Longitude</td>
<td>Acceleration X</td>
</tr>
<tr>
<td></td>
<td>Orientation X</td>
</tr>
<tr>
<td></td>
<td>Acceleration Y</td>
</tr>
<tr>
<td></td>
<td>Orientation Y</td>
</tr>
<tr>
<td></td>
<td>Acceleration Z</td>
</tr>
<tr>
<td></td>
<td>Orientation Z</td>
</tr>
<tr>
<td></td>
<td>Gyroscope X</td>
</tr>
<tr>
<td></td>
<td>Gyroscope Y</td>
</tr>
<tr>
<td></td>
<td>Gyroscope Z</td>
</tr>
</tbody>
</table>

Data format transferred through the cellular connection

Source: Gas Technology Institute
3.2 Data Management Architecture

A layout of the system deployed to continuously capture and process the data is shown in Figure 19. Data is transferred from the excavation equipment through the cellular connection every 5 seconds in data packets. These data packets create a data stream that is captured by the cloud server through a web socket router residing within the cloud server. Table 3 shows the data format from the hardware devices to the web socket. The components for the data management on the server side consist of the following:

- Web Socket is a communication protocol for two-way connectivity. Sensor data packet is received through the web socket whereas alarm notifications are sent back to the hardware device if the construction equipment appears to be digging in an area near buried infrastructure.
- Apache Kafka is an open-source distributed publish-subscribe message platform. It transports the data from the web socket to ‘Geo-Event’ processor for spatial analysis and to the Apache Spark to apply the machine learning algorithm.
- Apache Spark is an open-source big data in-memory computing framework. It is used in the excavation activity recognition by a machine learning algorithm. Prediction of any ‘digging’ activity by the construction equipment triggers an alarm which is sent to the dashboard and the hardware devices through the web socket router.
- ArcGIS is a web-based Esri server which incorporates the data from the Apache system for spatial analysis and displays it in the Operations Dashboard.

![Figure 19: System Architecture to Capture and Process Sensors Data](source: Gas Technology Institute)
Table 3: Data Format Transferred from the Hardware Device

<table>
<thead>
<tr>
<th>Attributes</th>
<th>Format Details</th>
</tr>
</thead>
<tbody>
<tr>
<td>Message ID</td>
<td>1 byte (0-255)</td>
</tr>
<tr>
<td>Padding</td>
<td>1 byte (0-255)</td>
</tr>
<tr>
<td>Device ID</td>
<td>4 bytes unsigned integer</td>
</tr>
<tr>
<td><strong>Spatial data</strong></td>
<td></td>
</tr>
<tr>
<td>Longitude</td>
<td>8 bytes IEEE 754 double float</td>
</tr>
<tr>
<td>Latitude</td>
<td>8 bytes IEEE 754 double float</td>
</tr>
<tr>
<td>Altitude</td>
<td>4 bytes IEEE 754 float</td>
</tr>
<tr>
<td>Num. Satellites</td>
<td>1 byte (0-255)</td>
</tr>
<tr>
<td>Fix Quality</td>
<td>1 byte (0-255)</td>
</tr>
<tr>
<td>Speed</td>
<td>4 bytes IEEE 754 float</td>
</tr>
<tr>
<td><strong>Time of observation</strong></td>
<td></td>
</tr>
<tr>
<td>Date-Time-Year</td>
<td>2 bytes (0-24)</td>
</tr>
<tr>
<td>Date-Time-Month</td>
<td>1 byte (1-12)</td>
</tr>
<tr>
<td>Date-Time-Day</td>
<td>1 byte (1-31)</td>
</tr>
<tr>
<td>Date-Time-Hour</td>
<td>1 byte (0-24)</td>
</tr>
<tr>
<td>Date-Time-Min</td>
<td>1 byte (0-60)</td>
</tr>
<tr>
<td>Date-Time-Sec</td>
<td>1 byte (0-60)</td>
</tr>
<tr>
<td>Bearing</td>
<td>4 bytes IEEE 754 float</td>
</tr>
<tr>
<td>Accel-X</td>
<td>4 bytes IEEE 754 float</td>
</tr>
<tr>
<td>Accel-Y</td>
<td>4 bytes IEEE 754 float</td>
</tr>
<tr>
<td>Accel-Z</td>
<td>4 bytes IEEE 754 float</td>
</tr>
<tr>
<td>Orient-X</td>
<td>4 bytes IEEE 754 float</td>
</tr>
<tr>
<td>Orient-Y</td>
<td>4 bytes IEEE 754 float</td>
</tr>
<tr>
<td>Orient-Z</td>
<td>4 bytes IEEE 754 float</td>
</tr>
<tr>
<td>Gyro-X</td>
<td>4 bytes IEEE 754 float</td>
</tr>
<tr>
<td>Gyro-Y</td>
<td>4 bytes IEEE 754 float</td>
</tr>
<tr>
<td>Gyro-Z</td>
<td>4 bytes IEEE 754 float</td>
</tr>
<tr>
<td>Temperature</td>
<td>2 bytes signed degree F</td>
</tr>
<tr>
<td>Cell Signal</td>
<td>1 byte (0-255)</td>
</tr>
<tr>
<td>Update Rate</td>
<td>2 bytes (0-65000) seconds</td>
</tr>
<tr>
<td>Status</td>
<td>1 byte (0-255) ‘alarm on / off’</td>
</tr>
</tbody>
</table>

Source: Gas Technology Institute

For the activity monitoring and recognition purposes, the primary attributes of interest are the date, time, location, speed, and the nine-degrees of freedom motion sensors data consisting of the acceleration, orientation, and gyro motions along the x, y, and z axes.

3.3 Devices Installed at Utility Sites

The device prototypes were evaluated under realistic field conditions at GTI testing facility and at PG&E’s natural gas service territory. Figure 20 shows the installation of the device on an excavator. The field tests were performed to evaluate the following:
- Installation procedure and placement of the devices in the cabins of various types of excavators
- Availability of power supply from the outlets of the cabins or hard wiring procedures to the equipment’s batteries if needed
- GPS and cellular signals strength and consistency
- Data display on the utility’s operation dashboard
- Evaluation of the motion sensors data for excavation recognition during equipment travel and excavation
- Alarm signals when the equipment is inside the marked geo-fence of a pipeline’s ROW
- Operator’s feedback about the operation and performance of the devices.

Figure 20: Placement of the GPS EEN Unit in the Excavator

Source: Gas Technology Institute

As the construction equipment performed activities, a researcher observed and recorded the details of activities and provided observation reports to further compare the records with the hardware sensors data. Excavators’ activities of idling, driving, and excavating were monitored and documented separately. A sample record of the excavation field monitoring report is shown in Appendix B.

The data was extracted from the server and analyzed. Sample graphs from the hardware sensors for various excavator activities are shown in Figures 21 to 23 for the acceleration, orientation, and gyro data, respectively. The figures show the correlations between the sensors data and the observed excavators actions (displayed on the x-axis time scale). These correlations are used to identify excavation activities from the sensors outputs in the following sections.
Figure 21: Time Plot of the Observations and Accelerometer Data

Source: Gas Technology Institute
Figure 22: Time Plot of the Observations and Orientation Data

Source: Gas Technology Institute
Figure 23: Time Plot of the Gyro Data from Excavator

Source: Gas Technology Institute
3.4 Excavation Activities Monitoring

3.4.1 Activities Categories:

Several devices were installed on various types of construction equipment and were monitored at PG&E excavation sites. The monitored excavation activities included the equipment’s start and end times, activity type, and additional details on equipment motion. Table 4 shows an example of an observation record. The observation records and hardware sensor data were later combined in a post-processing routine to correlate the data for each sensor record.

Table 4: Sample Field Observation of Activities

<table>
<thead>
<tr>
<th>Start Time</th>
<th>End Time</th>
<th>Digging</th>
<th>Driving</th>
<th>Idle</th>
<th>Other</th>
<th>Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td>8:10:53 AM</td>
<td>8:11:12 AM</td>
<td>YES</td>
<td>YES</td>
<td>YES</td>
<td></td>
<td>reverse</td>
</tr>
<tr>
<td>8:11:12 AM</td>
<td>8:11:44 AM</td>
<td>YES</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>8:11:44 AM</td>
<td>8:12:35 AM</td>
<td>YES</td>
<td></td>
<td></td>
<td></td>
<td>lift plate</td>
</tr>
<tr>
<td>8:12:35 AM</td>
<td>8:14:56 AM</td>
<td>YES</td>
<td></td>
<td></td>
<td></td>
<td>throttle down</td>
</tr>
<tr>
<td>8:14:56 AM</td>
<td>8:15:48 AM</td>
<td></td>
<td></td>
<td>YES</td>
<td></td>
<td>forward driving</td>
</tr>
<tr>
<td>8:15:48 AM</td>
<td>8:16:22 AM</td>
<td></td>
<td></td>
<td>YES</td>
<td></td>
<td>throttle down</td>
</tr>
<tr>
<td>8:16:22 AM</td>
<td>8:17:15 AM</td>
<td></td>
<td></td>
<td>YES</td>
<td></td>
<td></td>
</tr>
<tr>
<td>8:17:15 AM</td>
<td>8:17:58 AM</td>
<td></td>
<td></td>
<td>YES</td>
<td></td>
<td>lift plate</td>
</tr>
<tr>
<td>8:17:58 AM</td>
<td>8:18:38 AM</td>
<td></td>
<td></td>
<td>YES</td>
<td></td>
<td></td>
</tr>
<tr>
<td>8:18:38 AM</td>
<td>8:19:11 AM</td>
<td></td>
<td></td>
<td>YES</td>
<td></td>
<td>move plate 10-15 degrees right</td>
</tr>
<tr>
<td>8:19:11 AM</td>
<td>8:19:20 AM</td>
<td></td>
<td></td>
<td>YES</td>
<td></td>
<td>throttle down</td>
</tr>
<tr>
<td>8:19:20 AM</td>
<td>8:19:40 AM</td>
<td></td>
<td></td>
<td>YES</td>
<td></td>
<td>forward driving</td>
</tr>
</tbody>
</table>

Source: Gas Technology Institute

The construction equipment activities monitored in the field were divided into the four categories of Idle, Driving, Digging, and Other, as follows:

a) Idle activities: This category consists of any activity that signals no work by the construction equipment, including:
- Machine ignition is off
- Machine is throttled up or down and not moving but ignition is on
- Idling while bucket is in hole/trench while workers hand-dig dirt into bucket.

b) Digging activities: This category consists of any activity that potentially poses a risk to the buried gas facility, including:
- Using the bucket to scoop and dump excavated material
- Digging while throttling up/down
- Using the bucket to “punch” concrete, dirt, or break up hard rock
- Using bucket to “crawl” (backhoe repositioning)
- Lowering and raising bucket into hole/trench
- Pushing or moving backfill into trench or hole
- Compacting soil by tamping it with the bucket while backfilling
- Compacting the backfill by driving over it.
c) Driving activities: This category consists of any activity that repositions the construction equipment from one place to another without digging, including:
- Driving to reposition the machine
- Moving objects other than backfill.

d) Other activities: Any activity that does not fall under the previous three categories.

3.4.2 Data Collection from Equipment

Developing the activities recognition software consisted of a “training phase” where the field data was used to construct the algorithm and a “prediction phase” where the data were used to calibrate and define the activities. The training phase was performed using 18 datasets collected from various types of construction equipment at PG&E excavation sites. The datasets consisted of five backhoes and 13 excavators. Table 5 lists details of the datasets.

Figures 24 and 25 show the distribution of observation records by activities for backhoe and excavators, respectively. The most frequent records were collected for ‘Digging’ activity.

Table 5: Details of Datasets Used in Machine Learning

<table>
<thead>
<tr>
<th>Date</th>
<th>Device Name</th>
<th>Equipment Type</th>
<th>Location</th>
</tr>
</thead>
<tbody>
<tr>
<td>3/20/2017</td>
<td>GTI1008</td>
<td>Backhoe</td>
<td>Livermore, CA</td>
</tr>
<tr>
<td>3/20/2017</td>
<td>GTI1008</td>
<td>Excavator</td>
<td>Livermore, CA</td>
</tr>
<tr>
<td>3/20/2017</td>
<td>GTI1019</td>
<td>Backhoe</td>
<td>Livermore, CA</td>
</tr>
<tr>
<td>3/20/2017</td>
<td>GTI1019</td>
<td>Excavator</td>
<td>Livermore, CA</td>
</tr>
<tr>
<td>4/26/2017</td>
<td>GTI1015</td>
<td>Backhoe</td>
<td>Schooner Hill &amp; Clipper Hill, Oakland CA</td>
</tr>
<tr>
<td>5/22/2017</td>
<td>GTI1028</td>
<td>Backhoe</td>
<td>Sacramento St. &amp; Rose St., Berkeley CA</td>
</tr>
<tr>
<td>5/30/2017</td>
<td>GTI1004</td>
<td>Excavator</td>
<td>699 Van Buren Rd, Menlo Park, CA</td>
</tr>
<tr>
<td>6/7/2017</td>
<td>GTI1027</td>
<td>Excavator</td>
<td>1066 Bay Rd., Menlo Park, CA</td>
</tr>
<tr>
<td>6/20/2017</td>
<td>GTI1019</td>
<td>Excavator</td>
<td>48599 Fremont Blvd., Fremont CA</td>
</tr>
<tr>
<td>6/22/2017</td>
<td>GTI1006</td>
<td>Excavator</td>
<td>1990 Olivera Rd., Concord CA</td>
</tr>
<tr>
<td>6/26/2017</td>
<td>GTI1014</td>
<td>Excavator</td>
<td>Lundy Ave. &amp; Fortune Dr., San Jose CA</td>
</tr>
<tr>
<td>7/10/2017</td>
<td>GTI1019</td>
<td>Excavator</td>
<td>913 Sunset Dr., Antioch, CA</td>
</tr>
<tr>
<td>7/14/2017</td>
<td>GTI2024</td>
<td>Backhoe</td>
<td>Livermore, CA</td>
</tr>
<tr>
<td>7/17/2017</td>
<td>GTI1006</td>
<td>Excavator</td>
<td>85 El Molina Dr., Clayton CA</td>
</tr>
<tr>
<td>7/20/2017</td>
<td>GTI1006</td>
<td>Excavator</td>
<td>28-56 Weatherly Dr.,</td>
</tr>
<tr>
<td>7/24/2017</td>
<td>GTI1006</td>
<td>Excavator</td>
<td>41-59 El Molino Dr., Clayton CA</td>
</tr>
<tr>
<td>7/28/2017</td>
<td>GTI2031</td>
<td>Excavator</td>
<td>Livermore, CA</td>
</tr>
<tr>
<td>8/22/2017</td>
<td>GTI1006</td>
<td>Excavator</td>
<td>Marsh Creek Rd.,</td>
</tr>
</tbody>
</table>

Source: Gas Technology Institute
3.5 Activity Recognition Algorithm

The first step of developing a machine learning algorithm for activity recognition was to identify the patterns of the activities from the data. The time series characteristic of the data was evaluated and the nine-degrees of freedom were compiled in resultant acceleration, gyro, and orientation vectors. Their magnitudes are calculated as:

- Acceleration \( a = \sqrt{a_x^2 + a_y^2 + a_z^2} \)
- Gyro \( g = \sqrt{g_x^2 + g_y^2 + g_z^2} \)
- Orientation \( o = \sqrt{o_x^2 + o_y^2 + o_z^2} \)
3.5.1 Activity Patterns for Excavation Equipment

Figures 26 to 28 show the acceleration, gyroscope, and orientation data collected for “Idle”, “Digging”, and “Driving” activities of the backhoe, respectively. Further details about field data collection from the excavators were presented in an earlier task report. Distinct patterns were seen for each of the activities. As expected, the “Idle” activity had smooth graphs compared to the “Digging” and “Driving” activities. Driving activities had distinctive changes from 0 to 360 degrees in the orientation charts, characterizing the equipment turns during driving.

Figure 26: Acceleration, Orientation, and Gyroscope for ‘Idle’ Backhoe Activity

Source: Gas Technology Institute

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Farrag, Khalid; Marros, Robert; Sphar, Jason; Blitzstein, Steven; GTI (Gas Technology Institute). 2017. GPS Excavation Encroachment Notification System (GPS EENS), Installation Planning. Publication number: CEC-500-2018-xxx
Figure 27: Acceleration, Orientation, and Gyroscope for Digging Backhoe Activity

Source: Gas Technology Institute
3.5.2 Activity Patterns Algorithm

The data shown in the previous section were passed through a filter to remove any noise or outliers. The noise filter is a 7-point smoothing function which calculates each point to the average of its six nearest neighbors around the point.

The data from the activities were then inferred with a machine learning algorithm. The data stream contains spatial-temporal characteristics; location and time were important attributes. Geo-location of the equipment helps to identify whether to extract features from the data packets. Any data from outside the geo-fence area of buried pipe assets were not relevant for potential risk calculations. The temporal property of the data stream allowed for looking at data from a range of time stamps which gave a stronger indication of an activity than a single data point.

The training of the machine learning algorithm required a large amount of data to ensure that there was a sufficient amount of data points for each combination of activities. Two steps were used; the “training” step where data was extracted the features associated with each activity,
and the “prediction” step where data sets were used to predict the activity and add to the machine learning database for continuous enhancement (Figure 29).

To reduce the error rate, only data points whose speed measurements were less than four mph were considered for training and prediction. Construction equipment with speed greater or equal to four mph was classified in the driving activity.

**Figure 29: Machine Learning Algorithm Training and Prediction Process**

![Diagram of machine learning algorithm training and prediction process]

Source: Gas Technology Institute

### 3.5.3 Activity Recognition Validation

Validating the activities recognition algorithm was performed by matching the actual field observation labels against the predicted labels. The comparison resulted in one of these outputs:

- **True positive** \( t_p \) - both actual label and predicted label are positive.
- **True negative** \( t_n \) - both actual label and predicted label are negative.
- **False positive** \( f_p \) – actual label is negative and predicted label is positive.
- **False negative** \( f_n \) - actual label is positive and predicted label is negative.

Common metrics used for validation are:

- **Precision** = \( \frac{tp}{tp + fp} \)
- **Recall/Sensitivity** = \( \frac{tp}{tp + fn} \)
- **Specificity** = \( \frac{tn}{tn + fp} \)
- **Accuracy** = \( \frac{tp}{tp + fp} \)

For the validation, four datasets were used to calculate and plot the accuracy metrics for the three activities. Figures 30 and 31 show the absolute and relative accuracy results. The accuracy
percentages for idle, digging, and driving activities were 87 percent, 80 percent, and 85 percent, respectively.

**Figure 30: Absolute Accuracy Data of the Excavation Activities**

![Absolute Accuracy Data](image)

Source: Gas Technology Institute

**Figure 31: Relative Accuracy Data for Each of the Excavation Activities**

![Relative Accuracy Data](image)

Source: Gas Technology Institute

### 3.6 Agricultural Equipment Activities Monitoring

Two datasets were collected to train and test the machine learning algorithm for agricultural rippers. The process used in the activities recognitions of the agricultural equipment was similar to the one presented earlier for the excavators. The raw data was passed through a noise filter to remove any outliers. Next, features were extracted from the data to train the algorithm through the time series observations.

Initial analysis of the data showed that orientation and acceleration were the two essential metrics which differentiated digging activities from non-digging activities (Figures 32 and 33). The orientation data represented the back-and-forth pattern of the equipment during the...
ripping operation in the field. Acceleration and orientation features were given higher weights in the algorithm. The equipment speed was also used as a feature as it helped in distinguishing digging activity from idle activity (Figure 34). The figure shows an average speed of 3 mph during the equipment ripping operation in the field.

The algorithm was trained with 75% of data from the two datasets and tested with the remaining 25% of the data. Accuracy was calculated to be about 78% by comparing the observed activity with the predicted one.

**Figure 32: Observations for Agricultural Digging Activity**

![Acceleration observations](image1)

![Orientation observations](image2)

![Gyroscope observations](image3)

Source: Gas Technology Institute
Figure 33: Observations for Agricultural Idle Activity

Source: Gas Technology Institute
Figure 34: Statistical Average of Agricultural Equipment Speed

Source: Gas Technology Institute
CHAPTER 4:
EEN System Deployment

4.1 System Installation and Operation at PG&E

The GPS EEN system included the following:

- Installed the hardware and software on the utility excavators and equipment
- Deployed the system architecture and the web service support for data management
- Provided system documentation reports detailing the system hardware and software
- Performed system training for the utilities as required.

Of the 150 EEN devices, 130 were used at the PG&E natural gas service territory and a small set of 20 units were sent to SoCal Gas for deployment. The original development plan was to work only with PG&E in the project. When the device was built and demonstrated to SoCal, the engineers were interested in trying the units and 20 devices were sent to them. Figure 35 shows the installed device on an excavator at PG&E.

![Figure 35: Installation of the GPS EEN Unit in the Excavator](image)

Source: Gas Technology Institute

Field monitoring activities were recorded as the equipment performed excavations at the PG&E utility sites. A project subcontractor supervised the installations of the EEN units on the excavators, attended the excavation activities, and manually recorded the various activities in excavator field monitoring form. Excavators’ activities of idling, driving, and excavating were monitored and documented separately with their time stamp and duration. A sample of the “Excavator Field Observation Form” is in Appendix B.
The data from the motion sensors in the device was extracted from the server and analyzed. Correlations between the sensors data and the observed excavators’ actions were performed to verify that the algorithm established in the earlier chapter for identifying excavation activities was correct. Tables 6 and 7 show the data observation forms for backhoes and excavators, respectively. The data included the equipment start and end times, activity type, and details of equipment motion.

4.2 Activities Recognition and Awareness

The utilities dashboard provides historical and statistical data of the equipment activities. The data identifies areas with high potential encroachment, activities of specific equipment, and critical locations of the warning signals resulting from digging in the pipeline zones.

Figure 36 depicts historical excavation data of specific contractors’ equipment. The user may engage the “Time Slider Tool” to select a range of the historical dates of interest. The historical digging activity polygon in the figure changes as different date ranges are defined. This approach allows the user to pinpoint to recent digging activity.

Figure 37 provides a closer look of the digging activity based on the date range specified. As the user zooms in, different levels of digging concentrations are displayed.
# Table 6: Data Observation Form for Backhoes During Field Work

## GTI Excavator Testing

<table>
<thead>
<tr>
<th>Test #</th>
<th>Activity</th>
<th>Sub-activity</th>
<th>Description and Timing</th>
<th>Outrigging Deployed</th>
<th>Time Start</th>
<th>Time End</th>
<th>Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Idle</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1A</td>
<td>Low/regular</td>
<td>4 minutes at <em>900</em>____ RPMs</td>
<td></td>
<td></td>
<td>1228</td>
<td>1232</td>
<td>This is the RPM at which digging would take place.</td>
</tr>
<tr>
<td>1B</td>
<td>High</td>
<td>4 minutes at <em>2400</em>____ RPMs</td>
<td></td>
<td></td>
<td>1232</td>
<td>1236</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>Driving</td>
<td></td>
<td></td>
<td>N/A</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2A</td>
<td>On gravel drive</td>
<td>7 minutes total, drive 3.5 minutes pause 20 seconds and repeat. Drive at _____ mph.</td>
<td></td>
<td>N/A</td>
<td>1238</td>
<td>1244</td>
<td>4.5 minutes going slow (2nd gear) fast of time fast (3rd gear)</td>
</tr>
<tr>
<td>2B</td>
<td>Varying speeds</td>
<td>4 minutes total, drive 1 minutes pause 20 seconds and repeat three times. Start at lowest speed and accelerate to highest safe speed.</td>
<td></td>
<td>N/A</td>
<td>1246</td>
<td>1250</td>
<td>Travelled in same loop as test 2A, drove at random variable speeds.</td>
</tr>
<tr>
<td>3</td>
<td>Stopping</td>
<td>drive 20 ft, stop, reverse, stop</td>
<td>4 minutes total.</td>
<td></td>
<td>1251</td>
<td>1255</td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>Stationary</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>4A</td>
<td></td>
<td>Rotating cabin 360 degrees (excavator only)</td>
<td>Three rotations total, pause 20 seconds before repeating action.</td>
<td></td>
<td></td>
<td></td>
<td>SKIP</td>
</tr>
<tr>
<td>4B</td>
<td></td>
<td>Slow in 45 deg increments (excavator only)</td>
<td>3 minutes total, pause 20 seconds before repeating action.</td>
<td></td>
<td></td>
<td></td>
<td>SKIP</td>
</tr>
<tr>
<td>4C</td>
<td></td>
<td>While digging</td>
<td>4 minutes total. Pick up earth and drop, do not move dirt to another location.</td>
<td>X</td>
<td>1256</td>
<td>102</td>
<td>Noticed that cab of backhoe did not move very much. Sometimes the part of the cab where the device was mounted would lurch slightly. Dig was pressed during this test.</td>
</tr>
<tr>
<td>4D</td>
<td></td>
<td>Extend arm and back</td>
<td>3 minutes total, pause 30 seconds before repeating action.</td>
<td>X</td>
<td>102</td>
<td>108</td>
<td>Cab barely moves. I don’t think Dig was pressed.</td>
</tr>
<tr>
<td>5</td>
<td>Extend arm while excavating</td>
<td></td>
<td></td>
<td>X</td>
<td>107</td>
<td>107</td>
<td>The backhoe executed a repositioning maneuver.</td>
</tr>
<tr>
<td>5A</td>
<td></td>
<td>Dig, pickup, move, drop</td>
<td>5 minutes total.</td>
<td>X</td>
<td>109</td>
<td>114</td>
<td>Dig was pressed during this.</td>
</tr>
<tr>
<td>6</td>
<td></td>
<td>Moving and dragging equipment/dirt</td>
<td>3 minutes total.</td>
<td></td>
<td></td>
<td></td>
<td>SKIP</td>
</tr>
<tr>
<td>7</td>
<td></td>
<td>Backfill (Backhoe only)</td>
<td>10 minutes total.</td>
<td></td>
<td>117</td>
<td>117</td>
<td>To backfill the backhoe uses the bucket on the front of the equipment and drives around.</td>
</tr>
<tr>
<td>8</td>
<td></td>
<td>Deploy Outrigging (Backhoe only)</td>
<td>2 minutes total, pause 10 seconds before repeating action. Repeat deploying and retracting outrigging.</td>
<td></td>
<td>124</td>
<td>126</td>
<td></td>
</tr>
<tr>
<td>9</td>
<td>Obstacle Course</td>
<td></td>
<td>25-40 minutes total. Dig a <em>5_x_5</em> bell hole, pause 20 seconds, travel 20 ft, dig a 14 foot trench, pause 20 seconds, reposition with outrigging deployed (backhoe only), pause 20 seconds, backfill bell hole (backhoe only).</td>
<td>X</td>
<td>127</td>
<td></td>
<td>Dig was pressed just before deploying outrigging. @132 repositioned backhoe @144 bell hole complete @145 trenching started @150 repositioned to continue trench @154 repositioned to continue trench</td>
</tr>
</tbody>
</table>
Table 7: Data Observation Form for Excavators during Field Work

<table>
<thead>
<tr>
<th>Test #</th>
<th>Activity</th>
<th>Sub-activity</th>
<th>Description and Timing</th>
<th>Outrigging Deployed</th>
<th>Time Start</th>
<th>Time End</th>
<th>Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Idle</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1A</td>
<td>Driving</td>
<td>low/regular</td>
<td>4 minutes at LOW (1) RPMs</td>
<td></td>
<td>920</td>
<td>924</td>
<td>Will have to look at catalog to relate throttle level of 1 to RPMs</td>
</tr>
<tr>
<td>1B</td>
<td>Driving</td>
<td>high</td>
<td>4 minutes at HIGH (10) RPMs</td>
<td></td>
<td>930</td>
<td>935</td>
<td>Will have to look at catalog to relate throttle level of 10 to RPMs</td>
</tr>
<tr>
<td>2</td>
<td>Driving</td>
<td>On gravel drive</td>
<td>7 minutes total, drive 3.5 minutes pause 20 seconds and repeat. Drive at mph.</td>
<td></td>
<td>941</td>
<td>946</td>
<td>Was in “turtle” mode until 945 then “rabbit” mode for duration. Had boon in proper position to keep weight balanced.</td>
</tr>
<tr>
<td>2B</td>
<td>Driving</td>
<td>Varying speeds</td>
<td>4 minutes total, drive 1 minute pause 20 seconds and repeat three times. Start at lowest speed and accelerate to highest safe speed.</td>
<td></td>
<td>952</td>
<td>956</td>
<td>Did not drive and pause every 20 seconds as the procedure says.</td>
</tr>
<tr>
<td>3</td>
<td>Stopping</td>
<td>Drive 20 ft, stop, reverse, stop</td>
<td>4 minutes total</td>
<td></td>
<td>959</td>
<td>1003</td>
<td>For the first two back-and-forth drives the cab swung 180</td>
</tr>
<tr>
<td>4</td>
<td>Stationary</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>4A</td>
<td>Stationary</td>
<td>Rotating cabin 360 degrees (excavator only)</td>
<td>Three rotations total, pause 20 seconds before repeating action.</td>
<td></td>
<td>1004</td>
<td>1006</td>
<td>Did 5 rotations total. 2 then pause, 1 then pause, 1 then pause, 2 then pause.</td>
</tr>
<tr>
<td>4B</td>
<td>Stationary</td>
<td>Slow in 45 deg increments (excavator only)</td>
<td>3 minutes total, pause 20 seconds before repeating action.</td>
<td></td>
<td>1007</td>
<td>1009</td>
<td>Turned cab in 90 degree rotations instead of 45</td>
</tr>
<tr>
<td>4C</td>
<td>Stationary</td>
<td>While digging</td>
<td>4 minutes total. Pick up earth and drop, do not move dirt to another location.</td>
<td></td>
<td>1013</td>
<td>1017</td>
<td>During digging throttle would be set to maximum. The cab only moves slightly.</td>
</tr>
<tr>
<td>4D</td>
<td>Stationary</td>
<td>Extend arm and back</td>
<td>3 minutes total, pause 30 seconds before repeating action.</td>
<td></td>
<td>1021</td>
<td>1024</td>
<td>Without dirt the cab moves even less than in 4D. It will be interesting to compare this with 4D and with the two idle states.</td>
</tr>
<tr>
<td>5</td>
<td>Extend arm while excavating</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>5A</td>
<td>Extend arm while excavating</td>
<td>Dig, pickup, move, drop</td>
<td>5 minutes total.</td>
<td></td>
<td>1028</td>
<td>1034</td>
<td>SKIP</td>
</tr>
<tr>
<td>6</td>
<td>Moving and dragging equipment/dirt</td>
<td></td>
<td>3 minutes total</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>7</td>
<td>Backfill</td>
<td>(Backhoe only)</td>
<td>10 minutes total</td>
<td></td>
<td>1044</td>
<td>1045</td>
<td>The operator executes lots of fast movements. Uses small blade on excavator to complete this.</td>
</tr>
<tr>
<td>8</td>
<td>Deploy Outrigging</td>
<td>(Backhoe only)</td>
<td>2 minutes total, pause 10 seconds before repeating action. Repeat deploying and retracting outrigging.</td>
<td></td>
<td>1114</td>
<td>1114</td>
<td>Digging started @ 116 ended at 1128 @1130 traveled @1132 trenching until 1145 @1147 backfill</td>
</tr>
<tr>
<td>9</td>
<td>Obstacle Course</td>
<td></td>
<td>15-40 minutes total. Dig a <strong>S__x__S</strong> bell hole, pause 20 seconds, travel 20 ft, dig a 14 foot trench, pause 20 seconds, reposition with outrigging deployed (backhoe only), pause 20 seconds, backfill bell hole (backhoe only).</td>
<td></td>
<td>1114</td>
<td>1114</td>
<td></td>
</tr>
</tbody>
</table>

Source: Gas Technology Institute
Figure 38 shows a more detailed view of the data behind the polygon representations based on digging activity. At this zoom level, the collected data points show further details about their attributes. Once the user identifies which device they are analyzing, they can continue onto the “Query Tool” to select data from a specific day.

Figure 39 shows the query tool for a specific device. The query retrieves all data points collected for the device on a specific day. Figure 40 shows the results of the query tool compiled into a CSV file.

Figure 41 shows using the “Select Tool” to interactively select data points on the map. Once the data points are selected, the results can be exported to a CSV file.
Figure 38: Attributes of the Data Collection Point

Figure 39: Query Tool for Device and Date Search
4.3 System Installation and Operation at SoCal Gas

A set of 20 EEN devices was sent to SoCal Gas to install and use. A field demonstration was performed on November 2017 at the SoCal Gas testing facility to demonstrate the installation and registration of the devices and the operation dashboard. The demonstration presented the functionality of the system and the notifications, warnings, and alert messages as the devices interact with the utilities pipeline boundaries. Figure 42 shows the installation of the device on a utility excavator.

Figure 42: EEN Device Installation on a Utility Backhoe

An Esri Survey 123 application was used to register the EEN devices online. The application allows a broad team to track and identify each device and its attributes. Figure 43 shows an example of the data entered during the registration process.

An operation dashboard was provided to locate the devices, review installation and registration information, review historical data, and identify the operation status of each device. Primary and secondary boundaries were installed around the utilities pipelines. The device sounds an alarm and turns on flashing lights when the excavator enters a primary boundary. When a device enters a secondary boundary, the device would beep once and turn on lights.
The dashboard for SoCal Gas included the capability to send email notifications when a device is inside a primary boundary and is in the “digging” mode. Figure 44 shows an example of the email message. The message algorithm is currently being updated to prevent sending repeated email messages every five seconds which is the rate of monitoring the excavator activities.

**Figure 44: Sample Email Message of Device inside a Primary Boundary**

GTI2512 has entered the SoCal Project Boundary Primary/Slauson & Rosemead Blvd, Pico Rivera
This activity occurred @ Wed Jan 10 13:11:15 UTC 2018.

This email was generated by the Esri GeoEvent Processor

A “historical web application“ was also developed so the user can review all data collected by the devices during the previous seven days. The user can query for certain devices, select subsets of data, and export data records to a CSV file. Figure 45 shows an example of the web application.
Figure 45: Equipment Location Records in the Historical Web Application

Source: Gas Technology Institute
CHAPTER 5: Evaluation of Project Benefits

5.1 Executive Summary of Cost Analysis Approach

The GPS EEN technology implements a notification system which alarms the excavators and notifies the utilities when an excavation is being performed at or near a pipeline. The process increases the awareness of operating excavators and significantly reduces the risk of excavation damage to a utility infrastructure. The specific benefits of the project include:

- Improved pipeline integrity by reducing excavation damages to utilities infrastructure systems.
- Improved public safety by providing enhanced situational awareness to excavators operating within a utility’s service territory.
- Improved emergency response to pipeline incidents by providing near real-time mobile GIS asset information.
- Reduced methane emissions by preventing pipeline incidents resulting in natural gas leaks.

The following sections demonstrate estimated quantitative cost benefits of the GPS EEN technology. The cost-benefit analysis compared the estimated costs of developing, producing, and deploying the technology with the estimated financial consequences if the technology was not applied. The scope of the cost benefit analysis was limited to the following:

- Cost estimate of excavation damages in the California. This estimate was compared to the national estimates where applicable.
- Estimates of excavation damages in 2016. Average data from 2010 to 2016 were used where applicable to mitigate the annual variabilities of the data.
- Excavation damages to natural gas transmission and distribution systems; excluding damages to telecommunication, electrical, water, and other systems.
- Excavation damages from excavators which the technology applies to. This includes excavations performed by excavators, backhoes, and agricultural equipment and excludes excavations by hand digging and other drilling equipment.
- Estimated costs of damages to public and private properties, operator’s system, emergency response, and cost of released gas. Data on fatalities and injuries were listed when available but were not converted to financial estimates in the cost analysis.

Damage data was obtained from three different sources, namely: U.S. Department of Transportation (DOT) Pipeline and Hazardous Materials Safety Administration (PHMSA), California Public Utility Commission (CPUC) safety reports, and Common Ground Alliance (CGA) annual records.

Data from the three sources obtained more accurate information and resulted in stratifying the cost benefits to two damage estimates:
- Damages from significant incidents resulting in fatality, injury, or $50,000 or more in total costs
- Other non-significant damages in gas distribution system.

Excavation damages causing *significant incidents* in the natural gas system in California resulted in two fatalities and 13 injuries from 2010 to 2016. These incidents also resulted in an annual gas loss of 66,760 thousand cubic feet, and annual costs of about $2.1 million. This annual cost did not include the fatality and injury losses.

An average of 60% of the significant gas transmission incidents from 2010 to 2016 occurred with farm equipment and 16% with excavators and backhoes. First- and second-party excavators caused about 12% of these incidents.

In 2016, other *non-significant excavation incidents* to California’s gas distribution system were about 5,600 incidents according to PHMSA records and 5,175 to the CGA records. These incidents resulted in estimated costs of more than $30.6 million. CGA records show that 42.6% of these incidents were caused by backhoes and trenchers, with estimated cost of more than $13 million in 2016.

The estimated cost for the technology development is about $2 million. The cost of GPS EEN hardware and installation is estimated to be $200 and $300 per unit, depending on the number of units. Labor cost of technology mobilization and monitoring depends on the number of the EEN units deployed and differs per utility. Utility size and number of excavations occurring in its territory are significant factors in estimating these costs.

The benefits of the technology have already been seen with about 150 units installed in utilities’ and contractor’s excavators and in farm equipment. These installations address the damages caused by first-party and second-party excavations and agricultural equipment.

Further deployment by third-party contractors and agricultural equipment, in areas where gas pipeline systems exist, are anticipated in the next few years by commercializing the technology. Furthermore, telecommunication, electrical, and water industries using this technology would help foster awareness of this technology benefits and its effect on excavation safety.

### 5.2 Excavation Damage Cost Estimates

#### 5.2.1 PHMSA Records of Excavation Damage to Gas Pipeline System in California

The U.S. DOT PHMSA requires pipeline operators to annually report incidents of their pipeline systems caused by various pipeline threats. This section investigates the root causes and cost analysis of the PHMSA reported incidents resulting from excavation damage to gas distribution systems in California.

Table 8 shows the excavation damages reported by California Local Distribution Companies (LDC's) in 2016 categorized by the following apparent root causes of damage:

- **EXCAV_ONECALL**: One-Call notification practices not sufficient.
- **ESCAV_LOCATING**: Locating practices not sufficient.
- **EXCAV_EXCAV**: Excavation Practices not sufficient.
- **EXCAV_OTHER**: Other root causes of excavation damage.
- **EXCAV_DAMAGES**: Total number of excavation damages.

Table 8: Excavation Damage by Root Cause in California Gas Distribution in 2016

<table>
<thead>
<tr>
<th>OPERATOR_NAME</th>
<th>EXCAV_ONECALL</th>
<th>EXCAV_LOCATING</th>
<th>EXCAV_EXCAV</th>
<th>EXCAV_OTHER</th>
<th>EXCAV_DAMAGES</th>
<th>EXCAV TICKETS</th>
</tr>
</thead>
<tbody>
<tr>
<td>CITY OF SUSANVILLE</td>
<td>3</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>3</td>
<td>578</td>
</tr>
<tr>
<td>ISLAND ENERGY</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>132</td>
</tr>
<tr>
<td>ALPINE NATURAL GAS</td>
<td>4</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>4</td>
<td>261</td>
</tr>
<tr>
<td>COALINGA, CITY OF</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>WEST COAST GAS CO INC</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>293</td>
</tr>
<tr>
<td>LONG BEACH GAS DEPT, CITY OF</td>
<td>16</td>
<td>4</td>
<td>20</td>
<td>8</td>
<td>48</td>
<td>10,765</td>
</tr>
<tr>
<td>CITY OF VERNON</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>1,406</td>
</tr>
<tr>
<td>SAN DIEGO GAS &amp; ELECTRIC CO</td>
<td>161</td>
<td>24</td>
<td>133</td>
<td>87</td>
<td>405</td>
<td>123,726</td>
</tr>
<tr>
<td>SOUTHERN CALIFORNIA GAS CO</td>
<td>1,589</td>
<td>254</td>
<td>726</td>
<td>731</td>
<td>3,300</td>
<td>627,116</td>
</tr>
<tr>
<td>PACIFIC GAS &amp; ELECTRIC CO</td>
<td>860</td>
<td>204</td>
<td>734</td>
<td>8</td>
<td>1,806</td>
<td>858,972</td>
</tr>
<tr>
<td>PALO ALTO, CITY OF</td>
<td>13</td>
<td>8</td>
<td>11</td>
<td>3</td>
<td>35</td>
<td>5,131</td>
</tr>
<tr>
<td>SOUTHERN CALIFORNIA EDISON CO</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>6</td>
<td>159</td>
</tr>
<tr>
<td><strong>TOTAL</strong></td>
<td><strong>2,646</strong></td>
<td><strong>494</strong></td>
<td><strong>1,624</strong></td>
<td><strong>843</strong></td>
<td><strong>5,607</strong></td>
<td><strong>1,628,539</strong></td>
</tr>
</tbody>
</table>


The table shows about 5,600 excavation damages to gas distribution lines in California in 2016. The total number of excavation tickets reported by gas utilities in 2016 was 1,628,540 tickets.

The table shows that about 47% of the damage records were caused by failure to follow One-Call notification practices. Failure to follow correct practices of excavating near located pipes resulted in about 29% of the damages.

*Significant Incidents Resulting from Excavation Damage:*

Additionally, PHMSA regulations require natural gas pipeline companies to report significant incidents to their transmission and distribution systems. Significant Incidents are those including any of the following conditions:

- Fatality or injury requiring in-patient hospitalization.
- $50,000 or more in total costs, measured in 1984 dollars.
- Highly volatile liquid releases of five barrels or more or other liquid releases of 50 barrels or more.
- Liquid or gas releases resulting in an unintentional fire or explosion.

The average annual data from significant excavation damages are shown in Table 9. Table 10 shows the consequences of significant incidents in *gas transmission system* from 2010 to 2016. The table lists the losses categorized by fatality, injuries, gas release volume in thousand cubic feet.
(MCF), ignition, explosion, and public evacuation. The costs are categorized by the costs of operation, gas release, operator’s property, and emergency costs.

**Table 9: Average Annual Costs from PHMSA Significant Excavation Incidents**

<table>
<thead>
<tr>
<th>Consequence</th>
<th>Average Per Year</th>
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<tr>
<td>Number of Injuries</td>
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<td>Gas Ignition, in 1000 ft³</td>
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<tr>
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</tr>
<tr>
<td>Operator’s Property Damage</td>
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<td>Emergency costs</td>
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<td>Cost of Gas Released</td>
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<td>Total Annual Cost</td>
<td>$ 2,178,700</td>
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Source: Gas Technology Institute

Table 11 shows the root causes of these incidents. Most of these incidents were caused by third-party damage and about 12% were caused by first-party (utility-own excavators) and second-party (utility contractors) damages.

Similarly, the PHMSA reported significant incidents in the *gas distribution system* caused by excavation damage (Table 12). The table shows categorized costs of the estimated damage as follows:

- **Cost Operation ($)**: Estimated cost of public private property damage.
- **Cost Property ($)**: Estimated cost of operator’s property damage and repair.
- **Cost Emergency ($)**: Cost of operator emergency response.

The costs of significant incidents in PHMSA records are in current year dollars. Current year is the most recently completed calendar year. Value of gas lost was adjusted to current year dollars using the Energy Information Administration, Natural Gas City Gate Prices.

The data in tables 10 and 12 show total losses of significant transmission and distribution incidents are $15,250,916 from 2010 to 2016 in California, resulting in annual average costs of $2,178,700.
Table 10: Consequences of Significant Incidents in Gas Transmission System 2010 – 2016

<table>
<thead>
<tr>
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<th>FATALITY</th>
<th>INJURY</th>
<th>SHUTDOWN</th>
<th>IGNITION</th>
<th>EXPLOSION</th>
<th>PUBLIC EVACUATED</th>
<th>COST OPERATION ($)</th>
<th>COST GAS RELEASED ($)</th>
<th>COST PROPERTY ($)</th>
<th>COST EMERGENCY ($)</th>
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Table 11: Root Causes of Significant Incidents in Gas Transmission System 2010 – 2016

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<th>EXCAVATOR_EQUIPMENT</th>
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### Table 12: Consequences of Significant Incidents in Gas Distribution System 2010 – 2016

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<th>SHUTDOWNS</th>
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<td>NO</td>
<td>NO</td>
<td>0</td>
<td>150,000</td>
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<td>2014</td>
<td>4,021</td>
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<td>YES</td>
<td>NO</td>
<td>NO</td>
<td>20</td>
<td>500,000</td>
<td>5,000</td>
<td>24,124</td>
<td>24,124</td>
<td>525,624</td>
</tr>
<tr>
<td>2014</td>
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<td>0</td>
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<td>70,000</td>
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<td>21</td>
<td>21</td>
<td>70,021</td>
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<tr>
<td>2014</td>
<td>68</td>
<td>0</td>
<td>0</td>
<td>YES</td>
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<td>NO</td>
<td>0</td>
<td>67,203</td>
<td>0</td>
<td>364</td>
<td>364</td>
<td>67,567</td>
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<tr>
<td>2015</td>
<td>428</td>
<td>0</td>
<td>0</td>
<td>YES</td>
<td>NO</td>
<td>NO</td>
<td>13</td>
<td>50,000</td>
<td>0</td>
<td>1,838</td>
<td>1,838</td>
<td>51,838</td>
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<tr>
<td>2015</td>
<td>861</td>
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<td>YES</td>
<td>NO</td>
<td>NO</td>
<td>0</td>
<td>251,042</td>
<td>200</td>
<td>5,166</td>
<td>5,166</td>
<td>256,408</td>
</tr>
<tr>
<td>2015</td>
<td>3,185</td>
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<td>YES</td>
<td>NO</td>
<td>NO</td>
<td>100</td>
<td>37,081</td>
<td>0</td>
<td>19,113</td>
<td>19,113</td>
<td>56,194</td>
</tr>
<tr>
<td>2015</td>
<td>293</td>
<td>0</td>
<td>0</td>
<td>YES</td>
<td>NO</td>
<td>NO</td>
<td>0</td>
<td>163,600</td>
<td>0</td>
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<td>1,280</td>
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<tr>
<td>2015</td>
<td>240</td>
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<td>0</td>
<td>YES</td>
<td>NO</td>
<td>NO</td>
<td>12</td>
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<td>1,027</td>
<td>94,027</td>
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<td>0</td>
<td>YES</td>
<td>YES</td>
<td>NO</td>
<td>0</td>
<td>11,540</td>
<td>200</td>
<td>4,206</td>
<td>4,206</td>
<td>90,946</td>
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<td>2016</td>
<td>1,500</td>
<td>0</td>
<td>0</td>
<td>YES</td>
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<td>1</td>
<td>193,073</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>193,073</td>
</tr>
<tr>
<td>2016</td>
<td>330</td>
<td>0</td>
<td>0</td>
<td>YES</td>
<td>NO</td>
<td>NO</td>
<td>0</td>
<td>45,663</td>
<td>514,778</td>
<td>1,419</td>
<td>1,419</td>
<td>561,860</td>
</tr>
<tr>
<td>TOTAL</td>
<td>33,596</td>
<td>196</td>
<td>906,000</td>
<td>2,780,997</td>
<td>529,678</td>
<td>172,711</td>
<td>4,569,388</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

5.2.2 CBUC Records of Excavation Damage to Gas Pipeline System in California

The CPUC publishes annual safety reports which include investigations of incidents resulting in casualty, hospitalization, or damage. In comparison to the PHMSA records in the previous section, the CPUC records include other non-significant incidents which were reported by media coverage or recorded based on operator’s judgement.

The CPUC incident records for 2015 and 2016 show 275 reported incidents caused by excavation and third-party damages. However, these records are non-inclusive and include incidents which occurred in earlier years but still have on-going investigations. The records do not include estimated costs of damages but they provide root cause analysis of the damages.

A breakdown of the CPUC reported incidents in Figure 46 shows that third-party damage is the primary threat to gas pipelines.

**Figure 46: Reported Gas Service Safety Incidents in California by Threats**

- Outside Force: 35.5%
- Incorrect Operation: 2.6%
- Equipment Failure: 2.2%
- Corrosion: 0.4%
- Utility Excavation: 2.8%
- Other: 4.4%
- 3rd-Party Excavation: 52.0%

Source: Compiled from California Public Utilities Commission, Annual Reports, 2015 and 2016

5.2.3 CGA-DIRT Records of Excavation Damage to Gas Pipeline System in California

The CGA is an association consisting of 1,700 organizations and members of the underground pipeline utility industry. Established in 2000, CGA promotes best practices that lead to reductions in excavation damage and publishes annual Damage Information Reporting Tool (DIRT) which covers excavation damages reported in the United States and Canada.

The DIRT statistical excavation damage data for 2016 show the following national records:

- Estimate of 2016 total U.S. excavation damage records: 379,000.
- Estimated 2016 One-Call Center locate requests in U.S.: 32,560,000.
Each incoming locate request to a One-Call center results in several outgoing transmissions to facility operators, such as gas, electric, cable TV, telephone, sewer, and water. DIRT report estimates that the average number of transmissions per locate request is 6.62.

Based on the above data, the rate of excavation damage per transmission = \( \frac{379,000}{(32,560,000 \times 6.62) \div 1000} \) = 1.76 damages per 1,000 outgoing One-Call transmissions.

State average rates may differ widely from the above national rate since state laws differ in requiring notifications based on the type of work (such as hand tools or agriculture) or type of excavator (for example a homeowner). Additionally, state laws vary regarding number of contractors on a ticket, where several excavators on a worksite may share a single general contractor’s ticket.

**CGA-DIRT Estimates for Excavation Damage in California:**

Figure 47 shows the DIRT excavation damage data for California in 2016 and the following records:

- Estimated total damage in all utilities: 10,074
- Estimated damage to natural gas system: 5,175
- Estimated One-Call requests for all excavations in California: 1,950,000

The above data show a damage rate per 1,000 One-Call transmission = \( \frac{10,074}{(1,950,000 \times 6.62) \div 1000} \) = 0.78

DIRT report also provides an estimated average cost of $5,914 per natural gas facility damage. Accordingly, the estimated total cost of damage to natural gas facilities in CA is $5,914 \times 5,175 = $30,604,960 in 2016.

This estimated cost of excavation damage includes all excavator types. Figure 48 shows details of excavation damage by excavator type. Excavation damage caused by backhoes and trenchers (i.e., excluding drilling, hand tools, and other excavations) is estimated as 42.6%.

Since the GPS EEN technology targets losses to natural gas facilities caused by excavators and backhoes, the cost-benefit of using the technology is \( 30,604,960 \times 42.6/100 = 13,037,700 \). These losses are estimated in California based on 2016 data and they do not include the fatality and injury losses associated with excavation damage incidents.
Figure 47: Excavation Damage Data in California in 2016

![Facility Damaged Diagram]

Source: http://commongroundalliance.com/dirt-2016-interactive-report

Figure 48: Excavation Damage by Equipment Type in California, 2016

![Work Performed by Equipment Type Table]

Source: http://commongroundalliance.com/dirt-2016-interactive-report

5.3 Technology Benefits Estimates

Implementing the GPS EEN technology by the natural gas utilities in California provides the following benefits:
- **Cost:** The cost savings can be recognized from reduced incidents of pipeline excavation damage and improved emergency response. These savings are recognized by reduced consequences of loss of life, properties, and repair costs.
- **Environmental Impact:** The technology results in reduced emissions caused by leak damages to pipelines.
- **Efficiency gain:** It is expected that the technology will provide a higher efficiency in data capture and management of operations at and near the pipelines.

These benefits are quantified by the basic premise that using this technology will result in avoiding an incident or reducing the impact of an incident. By focusing on incidents on natural gas pipelines that resulted in death, injury and/or property damage, five major root causes emerged:

1. Failure to detect an existing defect. A defect may be the result of corrosion (internal or external), cracks dents or gouges, defective welds, or other anomalies.
2. Poor data and record keeping over the life of the asset. This includes the full range of data from the time the pipe or appurtenance is manufactured, through construction and installation to operations and maintenance activity.
3. Poor use of the data and records. Resulting in a lack of awareness of the presence or status of facilities as well as poor or low value analysis.
4. Failure to detect, locate, recognize, and respond to a leak or rupture in a timely basis.
5. Poor response or lack of a coordinated response to an incident.

The cost-benefit analysis of using the technology addresses significant and non-significant excavations damages. Significant incidents occurring within the natural gas system in California in 2016 resulted in gas release of about 66,760 thousand cubic feet, and average losses of $2,178,700. The cost-benefit of using the technology is estimated to address about 60% of the significant gas transmission incidents from farm equipment and 16% from excavators and backhoes.

Non-significant excavation incidents to gas distribution system in California in 2016 were about 5,175 incidents. These incidents resulted in estimated costs of $30,604,960. With 42.6% of these incidents caused by backhoes and trenchers, the cost-benefit of using the technology is $30,604,960 x 42.6% = $13,037,700.

The total estimated cost of funded projects of the technology is about $2 million. The cost of the GPS EEN device is estimated to be less than $300 per unit, depending on the number of units. Mobilization and monitoring costs differ according to the size of the utility and number of excavators in its territory.

Short-term benefits of using this technology has already happened with about 150 units installed in utilities’ and contractors’ excavators and backhoes, and farm equipment.
Completing the technology installations in first-party and second-party excavators and agricultural equipment would mitigate the estimated losses in these categories. These benefits estimates do not include fatality and injuries losses.

Further deployment by third-party contractors and agricultural equipment, in areas where gas pipeline systems exist, is anticipated by the commercializing the technology. Furthermore, deploying the technology by telecommunication, electrical, and water industries would provide significant recognition of the benefits and effect on excavation safety.

Implementing emergency response scenarios will also result in immediate benefit as communications to first responders become automated. Environmental conditions, accurate incident locations, and accurate GIS asset maps can be effectively communicated through the GPS EEN web system.

The assumptions associated with the quantification of the benefits of improved emergency response are as the following:

- Establishing high accuracy model of predicting the behavior of the excavators to provide more actionable information to the utility.
- Deploying the system in non-utility and general excavators to provide full situational awareness. Gas utilities in California are currently working with contractors and agriculture equipment operators to adopt the technology.
- Implementing effective and efficient communication protocols with link to the utilities GIS systems.
- Sharing information with other stakeholders, including emergency responders, one-call locators, and excavators.
CHAPTER 6: Technology Transfer Activities

6.1 Situational Awareness Plan

6.1.1 Introduction

Situational Awareness (SA) to incidents is knowledge of what is happening in the vicinity of the incident location and understanding how information, events, and actions will affect immediate and near future consequences. SA is especially important in natural gas pipeline accidents where information flow can be quite high and poor decisions may lead to serious consequences.\(^4\)

PHMSA natural gas pipelines significant incidents\(^5\) showed that nearly 60% of these incidents had some deficiencies in incident management. Table 13 shows the common deficiencies identified in pipeline incidents. The table shows that delays in the initial notification to emergency responders or pipeline operators were dominant or both. Common operation picture was lacking in more than 20% of the incidents. Improved communications during the planning and response phases of incidents would influence nearly all of the deficiencies noted.

**Table 13: Common Deficiencies Listed in Pipeline Incidents 1994-2011**

<table>
<thead>
<tr>
<th>Deficiency</th>
<th>% of Incidents</th>
</tr>
</thead>
<tbody>
<tr>
<td>Delayed notification to pipeline operator</td>
<td>19</td>
</tr>
<tr>
<td>Delayed notification to emergency responders</td>
<td>25</td>
</tr>
<tr>
<td>On-scene coordination problem between pipeline operator and emergency services</td>
<td>6</td>
</tr>
<tr>
<td>Delayed action by pipeline operator</td>
<td>9</td>
</tr>
<tr>
<td>Emergency service on-scene problem</td>
<td>13</td>
</tr>
<tr>
<td>Pipeline operator on-scene problem</td>
<td>3</td>
</tr>
<tr>
<td>Other deficiencies not listed above</td>
<td>13</td>
</tr>
</tbody>
</table>


---


Operation planning aims at providing a “common operational picture” (COP) to support a consistent awareness among all the organizations acting in an emergency event. A single COP displaying the GIS location of the pipeline and other relevant infrastructures would facilitate collaborative planning and execution. Using the EEN Operations Dashboard can be enhanced to include such information and provide a COP platform.

6.1.2 Common Operation Picture Layout

Using spatial data developed in the EEN Operation Dashboard can provide operators with comprehensive information for a COP plan. This data can be compiled in a GIS platform containing the locations of pipelines and their relevance to other nearby features. GTI has developed this functionality in a centralized situational awareness platform using the data, technologies, and methodologies listed below:

a) Data for Static and Streaming Information:

- Real time high accuracy mapping of utility infrastructure (Static Web Map Layer).
- Road closures (Active Streaming Data Layer from Field Collection).
- Nearest hospitals, fire stations, schools, and police stations (Static Web Map Layer).
- Current and future weather forecast (Active Streaming Layer from Weather Service).
- Residences and critical facilities within proximity of incident (Static Web Map Layer).
- Water and gas leaks (Active Streaming Data Layer from Field Collection).
- Real time locations of EEN devices.

b) Technologies:

- ArcGIS Server technology for publishing data services.
- ArcGIS WebApp Builder Application.
- Custom WebApp Builder Widgets.

c) Methodology:

- Streaming data coming live via the EEN devices and application
- Streaming data coming live from the high accuracy mapping projects in the field
- Creating a web application using ArcGIS Web App Builder that would use the map and feature services, located in control room and on mobile devices in the field
- Custom-creating widgets added for situational awareness analytics, such as proximity searches, buffers, and services in the immediate area
- Adding a secondary online Operations Dashboard in the control room for live data interaction.

d) Events and Notifications:

---

Using ArcGIS GeoEvent model for streaming data, geofence boundaries, and alerts

Inputting 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

Outputting from the GeoEvent Processor to feed data and alerts back to other systems being used within the situational awareness program.

6.1.3 Organizations Roles

A situational awareness plan also identifies how information can best be relayed from the sources to the people in charge who must make key decisions. An information flow analysis identifies who requires a particular type of information and the best means of providing it. An example of the flow analysis is shown in Figure 49.

Figure 49: Organizations Roles in Information Flow Chart

<table>
<thead>
<tr>
<th>Control of Pipeline Release</th>
<th>Environmental Protection Support</th>
<th>First Arriving Responder</th>
<th>Command/Interagency Coordination</th>
<th>Initial Receipt of Notification</th>
<th>Public Protective and Response Actions</th>
<th>Public Safety Call Taking and Dispatch</th>
</tr>
</thead>
<tbody>
<tr>
<td>Emergency Management</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Emergency Medical Service</td>
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<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Fire Department</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Law Enforcement Agency</td>
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<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Pipeline Operator</td>
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<td>X</td>
<td>X</td>
<td></td>
<td></td>
</tr>
<tr>
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<td></td>
<td></td>
</tr>
<tr>
<td>State pipeline regulatory agency</td>
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<td></td>
<td></td>
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<td></td>
<td></td>
</tr>
<tr>
<td>U.S. Coast Guard</td>
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<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>U.S. Environmental Protection Agency</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>No Defined Role</td>
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<td></td>
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</tr>
</tbody>
</table>

6.2 Technology Commercialization Efforts

The GPS EEN technology demonstrated how it could reduce the likelihood of excavation damage. The system alerts the utility and the equipment operator when excavation occurs on, or nearby, a pipeline location. Feedback from presenting this pilot study at the Western Regional Gas Conference of the American Gas Association (Appendix C) has been positive and interest has increased within the Natural Gas industry [7].

GTI is a not-for-profit entity that licenses its technology to entities to commercialize. At this time, the two pathways to market for the EEN system are to license the technology to either an existing technology provider or a startup entity. Commercialization efforts implemented the following approach:

- Interviewed the contractors and operators to identify potential partnerships with GIS system companies
- Demonstrated Webinars to generate additional feedback around commercial product pathway, determine potential business models, and identify other key risks
- Created a commercialization strategy to bring the technology to market and discuss and negotiate with potential commercial entities.

The excavator industry is competitive. Per *Equipment Watch* analysis, Caterpillar, Deere, and Komatsu are the leading suppliers with the market shares (Figure 50).

**Figure 50: Market Share for Hydraulic Excavators**


The research team attended the International Construction & Utility Equipment Exposition (ICUEE) in Louisville, Kentucky in 2017 and conducted interviews with the excavator manufacturers Caterpillar, Komatsu, Deere, Case, Danfoss, Volvo, and Hyundai. These interviews identified the top three GPS/Telematic companies which supply onboard solutions to the market (Table 14).

**Table 14: Selected GPS/Telematic Commercializers**

<table>
<thead>
<tr>
<th>Company</th>
<th>Type of Operation</th>
<th>Website</th>
</tr>
</thead>
<tbody>
<tr>
<td>Trimble</td>
<td>Trimble integrates a wide range of positioning technologies including GPS, laser, optical, and inertial technologies with application software, wireless communications, and services to provide complete commercial solutions</td>
<td><a href="http://www.trimble.com">www.trimble.com</a></td>
</tr>
<tr>
<td>Topcon</td>
<td>Topcon operates in the Positioning Business, which uses high-precision GNSS positing technology to achieve the automation of civil engineering construction and farming, and the Smart Infrastructure Business, which applies the surveying technology in the fields of infrastructure development and structural maintenance and management.</td>
<td><a href="http://www.topcon.com">www.topcon.com</a></td>
</tr>
<tr>
<td>Leica</td>
<td>Produces products and systems for surveying and geographical measurement (geomatics). Its products employ a variety of technologies including GPS satellite navigation and laser rangefinders to enable users to model existing structures, terrains in computer based systems to high accuracies.</td>
<td><a href="http://www.leica-geosystems.com">www.leica-geosystems.com</a></td>
</tr>
</tbody>
</table>

Caterpillar and Trimble formed a Joint Venture in 2002 - Caterpillar-Trimble Control Technologies. This joint venture develops advanced electronic guidance and control products for earthmoving machines. The other GPS/Telematics companies identified such as TopCon, Leica, Hitachi, and Proemion have a vendor/supplier relationship with the excavator manufacturing companies.

GTI and PG&E had in-depth discussions and hosted webinar demonstrations with Caterpillar-Trimble and other industries to identify how to produce and commercialize this technology, develop potential business models, and discuss partnership opportunities. These webinar demonstrations uncovered concerns regarding data standards, privacy/security of information, access to utilities GPS/GIS data, and how the EEN software would work with a company’s existing cloud-based infrastructure. Field interviews and webinar discussions delivered the insight necessary to refine the commercialization strategy.
GTI has also discussed a potential commercialization path with Elecsys Corporation, a leading provider of machine-to-machine (M2M) technology solutions and custom industrial electronics. Elecsys offers hardware solutions for the oil, gas, and water industry with applications for Cathodic Protection, Sensor/Transducer Monitoring, and Industrial data communications. Elecsys offers “Elecsys Connect,” a web/mobile app solution to monitor and control hardware solutions in real time. Elecsys is a strong candidate to commercialize the EENS product as the company currently services the oil and gas industry, has the capability to design and manufacture field ready hardware components, and has experience with real-time data acquisition and display to its customers.

Elecsys became aware of the GPS Excavation Encroachment Notification solution when they attended a presentation on the CEC GPS EEN project at the Western Regional Gas Association Conference in August 2017.

GTI and Elecsys held initial conversations in October followed by a demonstration of the system in November 2017. After the demonstration, GTI met in-person with Elecsys personnel in Olathe, Kansas in December 2017. The meeting provided an opportunity to demonstrate the system and answer questions about the Energy Commission Pilot Project with PG&E. Future commercialization plans are expected to continue with Elecsys regarding this opportunity.

Tensing is another privately held company based in the Netherlands with offices in the U.S. Tensing delivers GIS solutions using the Esri ArcGIS and Safe Software FME, leveraging these two platforms to create geospatial information and communicate this data to different applications. Tensing is also a strong candidate to commercialize the EENS product since the company has experience working with utilities, experienced with the Esri platform, and also offers a mobile application.

### 6.2.1 Future Commercialization Plans

Feedback from the market, and potential partners, necessitates an industry-led initiative to address some of the key concerns. GTI, with PG&E and SoCal Gas plan to create an industry-led working group to lay the foundation of a commercial test market. They would invite key stakeholders to create a framework to address safety and communication standards and include organizations like California Energy Commission, PHMSA, USA North/ 811 Call Service, and Gold Shovel Standard. This industry-led working group will help set the guidelines for the commercial entity to operate and bring online the EEN technology.

GTI will continue discussions and negotiations with interested parties to license the EEN technology. The commercial entity would establish a viable business model with the natural gas industry. Having gas utilities as anchor customers would give the commercial entity credibility, refine the business model and address key operational issues, such as launching and servicing

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the EEN technology. Other industries of interest include electric utilities, water & sewage, telecommunications, agriculture, and insurance. These industries benefit from the EEN technology with improved safety, reducing losses from accidents and business interruption through improved communication and monitoring.

6.3 Technology Knowledge Transfer

GTI has presented the technology at several conferences and meetings organized by members of these groups and industries: the GIS industry, the Common Ground Alliance, and several natural gas distribution utilities. Table 15 shows a list of these presentations.

Additionally, a patent application was submitted for the “Integrated System and Method to Determine Activity of Excavation Equipment”. This application is a follow up of an earlier provisional patent application No. 62/371,051 for the technology.

<table>
<thead>
<tr>
<th>Type</th>
<th>Title</th>
<th>Publication/Conference</th>
<th>Date</th>
<th>Presenter/Author</th>
<th>Location</th>
</tr>
</thead>
<tbody>
<tr>
<td>Presentation</td>
<td>Reducing Excavation Damage in the Gas Industry Using Real-Time GIS</td>
<td>Esri User Conference</td>
<td>7/12/2017</td>
<td>GTI</td>
<td>San Diego, CA</td>
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<td>[Attachment A]</td>
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</tr>
<tr>
<td>Paper/Poster</td>
<td>Reducing Third-Party Damage in the Natural Gas Industry Using Real-Time GIS and Sensors</td>
<td>International Gas Union Research Conference</td>
<td>5/24/2017</td>
<td>GTI</td>
<td>Rio de Janiero, Brazil</td>
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<tr>
<td>Presentation</td>
<td>GPS-Based Dig-In Prevention System</td>
<td>Western Regional Gas Conference [Attachment C]</td>
<td>8/8/2017</td>
<td>PG&amp;E and GTI</td>
<td>San Diego, CA</td>
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<td>Presentation</td>
<td>GPS-Based Transmission Dig-in Prevention</td>
<td>California Regional Common Ground Alliance</td>
<td>6/13/2017</td>
<td>PG&amp;E and GTI</td>
<td>Oakland, CA</td>
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<tr>
<td>Paper</td>
<td>International Pipeline Conference</td>
<td>Abstract accepted</td>
<td>September 2018</td>
<td>PG&amp;E and GTI</td>
<td>Calgary</td>
</tr>
<tr>
<td>Paper</td>
<td>Pipeline Conference</td>
<td>Word Gas Conference</td>
<td>June 2018</td>
<td>GTI</td>
<td>Washington, D.C.</td>
</tr>
</tbody>
</table>
GLOSSARY

The following table provides a sample of the terms used in the project reports:

<table>
<thead>
<tr>
<th>Term</th>
<th>Definition</th>
</tr>
</thead>
<tbody>
<tr>
<td>AGA</td>
<td>American Gas Association</td>
</tr>
<tr>
<td>ArcGIS</td>
<td>Online Cloud-Based Mapping Platform by Esri</td>
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<tr>
<td>CEC</td>
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<td>CFR</td>
<td>Code of Federal Regulations</td>
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<td>CGA</td>
<td>Common Ground Alliance</td>
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<tr>
<td>COP</td>
<td>Common Operational Picture, in Situational Awareness</td>
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<td>CPUC</td>
<td>California Public Utilities Commission</td>
</tr>
<tr>
<td>DIRT</td>
<td>Damage Information Reporting Tool</td>
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<tr>
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<td>Department of Transportation</td>
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<td>Excavation Encroachment Notification</td>
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<td>GIS</td>
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<td>M2M</td>
<td>Machine-to-Machine Technology</td>
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<td>Pacific Gas and Electricity Company</td>
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<tr>
<td>PHMSA</td>
<td>Pipeline and Hazardous Materials Safety Administration</td>
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<tr>
<td>ROW</td>
<td>Right-of-Way</td>
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<tr>
<td>SA</td>
<td>Situational Awareness</td>
</tr>
<tr>
<td>SoCal Gas</td>
<td>Southern California Gas company</td>
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REFERENCES


California Senate Bill SB 887, Chapter 673, 2015.


Farrag, Khalid; Marros, Robert; Sphar, Jason; Blitzstein, Steven; GTI (Gas Technology Institute). 2017. GPS Excavation Encroachment Notification System (GPS EENS), System Implementation Plan. Publication number: CEC-500-2017-xxx.

Farrag, Khalid; Marros, Robert; Sphar, Jason; Blitzstein, Steven; GTI (Gas Technology Institute). 2017. GPS Excavation Encroachment Notification System (GPS EENS), Installation Planning. Publication number: CEC-500-2017-xxx.


APPENDIX A:
Project Statements of Work

TASK 2 - IMPLEMENTATION PLANNING
The goal of this task is to identify and define the components required to complete an implementation of the EENS. Specifically, this includes the required infrastructure, workflows, communication procedures, training requirements and the deployment plan.

The Recipient shall:
- Develop and finalize the excavator hardware device design
- Design the system architecture
- Develop the communications protocol design for the utility
- Define the operational modeling/workflow
- Design the situational awareness application process
- Define the communication protocol for situational awareness
- Identify the third party/situation awareness entities
- Develop training requirements for the utility
- Prepare and submit a Deployment Plan Report which includes details of system components, design, and deployment
- Finalize the Deployment Plan Report
- Prepare a CPR Report #1 in accordance with Subtask 1.3 (CPR Meetings)
- Participate in a CPR meeting

Products:
- Deployment Plan (draft and final)
- CPR Report #1

TASK 3 - INSTALLATION PLANNING
The goal of this task is to complete the build out of the system architecture from Task 2. This task will also complete the configuration of the system components, configure third-party access and test the system for deployment of the entire system.

The Recipient shall:
- Acquire the hardware for the server environment, excavator sensor and communication package
- Build the system architecture as defined in Task 2
- Configure the software components
- Configure the system (hardware, software application, server environment)
- Acquire licenses for software operation
- Integrate GPS EENS and processes with the utility systems
- Configure third-party access (mapping, supporting communications)
- Develop a system test plan and perform the testing
- Prepare and submit a System Test Plan Report detailing the results of the test
- Prepare a CPR Report #2 in accordance with Subtask 1.3 (CPR Meetings)
- Participate in a CPR meeting
Tasks:
- System Test Plan Report
- CPR Report #2

**Task 4 - System Deployment**

The goal of this task is to deploy and demonstrate the system. This task will support installation of the required hardware in the field and installation of the Environmental Systems Research Institute (Esri) Operations Dashboard software required for real-time monitoring of field devices. This task will also deliver the system documentation and system training for users and stakeholders of the system. This task will also incorporate operations, analytical support and system maintenance.

**The Recipient shall:**
- Install hardware and software on the appropriate utility excavators and equipment
- Deploy the system architecture
- Prepare and submit a System Documentation Report detailing system hardware and software, and includes system deployment details and instructions
- Perform System Training for the utility field and office personnel
- Prepare a system validation test plan
- Perform the system validation tests and optimize system
- Finalize and submit the System Documentation Report which includes system validation test plan and results of system validation tests
- Provide on-going operational and analytics support
- Perform system maintenance as required
- Prepare a CPR Report #3 in accordance with Subtask 1.3 (CPR Meetings)
- Participate in a CPR meeting

Products:
- System Documentation Report
- CPR Report #3

**Task 5 - Evaluation of Project Benefits**

The goal of this task is to report the benefits resulting from this project.

**The Recipient shall:**
- Complete three Project Benefits Questionnaires that correspond to three main intervals in the Agreement: (1) Kick-off Meeting Benefits Questionnaire; (2) Mid-term Benefits Questionnaire; and (3) Final Meeting Benefits Questionnaire
- Provide all key assumptions used to estimate projected benefits, including targeted market sector (e.g., population and geographic location), projected market penetration, baseline and projected energy use and cost, operating conditions, and emission reduction calculations. Examples of information that may be requested in the questionnaires include:
  - For Product Development Projects and Project Demonstrations:
    - Published documents, including date, title, and periodical name

A-2
• Estimated or actual energy and cost savings, and estimated statewide energy savings once market potential has been realized. Identify all assumptions used in the estimates.
• Greenhouse gas and criteria emissions reductions
• Other non-energy benefits such as reliability, public safety, lower operational cost, environmental improvement, indoor environmental quality, and societal benefits
• Data on potential job creation, market potential, economic development, and increased state revenue as a result of the project
• A discussion of project product downloads from websites, and publications in technical journals
• A comparison of project expectations and performance. Discuss whether the goals and objectives of the Agreement have been met and what improvements are needed, if any

Additional Information for Product Development Projects:
  o Outcome of product development efforts, such as copyrights and license agreements
  o Units sold or projected to be sold in California and outside of California
  o Total annual sales or projected annual sales (in dollars) of products developed under the Agreement
  o Investment dollars/follow-on private funding as a result of Energy Commission funding
  o Patent numbers and applications, along with dates and brief descriptions

For Information/Tools and Other Research Studies:
• Outcome of project
• Published documents, including date, title, and periodical name
• A discussion of policy development. State if the project has been cited in government policy publications or technical journals, or has been used to inform regulatory bodies
• The number of website downloads
• An estimate of how the project information has affected energy use and cost, or have resulted in other non-energy benefits
• An estimate of energy and non-energy benefits
• Data on potential job creation, market potential, economic development, and increased state revenue as a result of project
• A discussion of project product downloads from websites, and publications in technical journals
• A comparison of project expectations and performance. Discuss whether the goals and objectives of the Agreement have been met and what improvements are needed, if any

Products:
• Kick-off Meeting Benefits Questionnaire
• Mid-term Benefits Questionnaire
• Final Meeting Benefits Questionnaire

TASK 6 Technology/Knowledge Transfer Activities
The goal of this task is to develop a plan to make the knowledge gained, experimental results, and lessons learned available to the public and key decision makers.

The Recipient shall:
• Prepare an *Initial Fact Sheet* at start of the project that describes the project. Use the format provided by the CAM
• Prepare a *Final Project Fact Sheet* at the project’s conclusion that discusses results. Use the format provided by the CAM
• Prepare a *Technology/Knowledge Transfer Plan* that includes:
  o An explanation of how the knowledge gained from the project will be made available to the public, including the targeted market sector and potential outreach to end users, utilities, regulatory agencies, and others
  o A description of the intended use(s) for and users of the project results
  o Published documents, including date, title, and periodical name
  o Copies of documents, fact sheets, journal articles, press releases, and other documents prepared for public dissemination. These documents must include the Legal Notice required in the terms and conditions. Indicate where and when the documents were disseminated
  o A discussion of policy development. State if project has been or will be cited in government policy publications, or used to inform regulatory bodies
  o The number of website downloads or public requests for project results
  o Additional areas as determined by the CAM
• Conduct technology transfer activities in accordance with the Technology/Knowledge Transfer Plan. These activities will be reported in the Progress Reports
• When directed by the CAM, develop *Presentation Materials* for an Energy Commission-sponsored conference/workshop on the results of the project
• Provide at least (6) six High Quality Digital Photographs (minimum resolution of 1300x500 pixels in landscape ratio) of pre and post technology installation at the project sites or related project photographs
• Prepare a *Technology/Knowledge Transfer Report* on technology transfer activities conducted during the project

**Products:**
• Initial Fact Sheet (draft and final)
• Final Project Fact Sheet (draft and final)
• Presentation Materials (draft and final)
• Technology/Knowledge Transfer Plan (draft and final)
• Technology/Knowledge Transfer Report (draft and final)
APPENDIX B:
Excavator Field Monitoring Report (Sample Record)

GPS Dig-In Prevention (EEN)
Observation Report
2017-09-15
PG&E Oakland General Construction

Details of Observation

<table>
<thead>
<tr>
<th>Company</th>
<th>PG&amp;E Oakland General Construction</th>
</tr>
</thead>
<tbody>
<tr>
<td>Location</td>
<td>Intersection of Miles Ave. &amp; Clifton (5273 Miles Ave., Oakland CA)</td>
</tr>
<tr>
<td>Date</td>
<td>September 14, 2017</td>
</tr>
<tr>
<td>Time (Start Time – End Time)</td>
<td>9:21:57am – 2:32:10pm</td>
</tr>
<tr>
<td>EEN Device Number</td>
<td>2006</td>
</tr>
<tr>
<td>Equipment Make and Model</td>
<td>John Deere 310J</td>
</tr>
<tr>
<td>Contact 1 (Name, position, email, phone number)</td>
<td>Scott Macias, Foreman, 510-303-8519</td>
</tr>
<tr>
<td>Contact 2 (Name, position, email, phone number)</td>
<td>David Billoups, Operator, 510-316-4382</td>
</tr>
</tbody>
</table>
Picture of Excavation Machine

Picture of EEN Device in the Machine

This picture shows the EEN device with the screen visible

This picture shows the EEN device with the ID visible
Picture showing EEN device installation

Explorer App Screen Shot of Device on the map
Explorer App Screen Shot of Device Pop-up Window

Explorer App Screen Shot of Job Location

Map is annotated to show the job site boundaries and the approximate location of digging. Stars indicate bell holes, lines indicate trenches, boxes indicate job boundaries.
Pictures of Job Location

Picture is annotated the approximate location of digging. Stars indicate bell holes, lines indicate trenches.

Picture of Trench dug at intersection of Miles Ave. & Clifton

Picture is annotated the approximate location of digging. Stars indicate bell holes, lines indicate trenches.

Picture of trench with shoring
Pictures of Job Location

Picture is annotated the approximate location of digging. Stars indicate bell holes, lines indicate trenches.

Pictures of Machine Digging
Pictures Showing Additional Observations

Picture showing bucket used to pull main underneath plates and underneath shoring

Bucket used to move dirt from truck bed and backfill a portion of the trench
APPENDIX C:
Western Regional Gas Conference (Presentation)

GPS-based Dig-In Prevention System
Gas Technology Institute and PG&E
August 8th 2017

Transmission dig-ins are an important problem.

They are rare but have large impacts...

- 118 significant gas dig-ins in US since 2010
- 27 significant incidents since 2010
- 15 injuries, 2 fatalities
- $10.8MM in damages
- 71% involved farming equipment and backhoes

... and they are preventable.

CA significant dig-in root-cause attribution % of incidents
- Notification: 11%
- Excavating: 30%
- Other: 52%
- Locating: 7%

We already do a lot to prevent these incidents.

Are we doing enough?
What if we could use GPS to raise awareness?

Automated alerts as an additional line of defense against dig-ins.

GTI has built this system and PG&E is testing it.

https://gti.maps.arcgis.com/apps/setdashboard/index.html?0276d0243375c43b2075191a6c6a51772

C-3
Key Features of the Device

- Mounts and Installs Easily
- Powered by 12V Plug
- Rugged, Weatherproof Body
- Integrated Audible Alarm
- Bright LED Warning Lights.

- GPS and Motion Sensor
- Delivers Tailored Alerts
- Status Screen
- Robust 2-way Communication

Key Features of the System

- Device
- Receive Data Stream
- Spatial Analysis

- Operator Alert
- Characterize Data
- Machine Learning

- Stakeholder Notification
- Awareness
Key Features of the Awareness Dashboard

Is this system too complicated to use?

- Simple Alert
- Sound and Flashing light

IF SAFE...

IF UNAWARE...

Pipe Buffer
Is this going to create too many alerts?

The CEC grant led to great progress.

Who 2nd and 3rd parties

Outcome Deploy 150 devices on excavators, backhoes, and tractors working in construction or agriculture

Goals Prove the technology in real-world. Identify a commercialization partner.
Highlights from the CEC Project

54 Dig-In Devices Deployed to Date
17 Deployment Partners
40 Project Stakeholders
3 Project Data/Awareness Dashboards
5 Months of Field Experience
9M Data Points Collected

Technology without commercialization...

Innovation = Invention + Commercialization

Vs.
Commercial Vision

Technology is on a commercialization path.
How do you get to zero?

Potential Accidents

What is the hold up?
Regulatory Advocates

Current Solution: Early Warning System

- Simple Alert
- Sound and Flashing light
- Acknowledge button

- Simple Email Alert
- Location based
- Possible Threat
- No advanced risk assessment

Pipe Buffer
Future Solution: Advanced Threat Detection

- Different Risk-Based Alerts
- Dashboard or Mobile
- Includes Detailed Information: Who, Activity, USA Ticket, HCA, Standby, etc.

Use Case: Equipment Operator

Benefits
- Enhanced safety
- Avoided incidents
- Simple to use and understand

Pipe Buffer

• Simple Alert
• Sound and Flashing light
• Acknowledge button
Use Case: Equipment Owner/Manager/Foreman

- Simple Alert
- Location based
- Possible Threat
- No advanced risk assessment

Benefits
- Enhanced safety
- Avoided incidents/costs
- Preferred insurance rates

Use Case: Utility (Future State)

- Different Risk-Based Alerts
- Includes Detailed Information: Who, Activity, USA Ticket, HCA, Standby, etc.
- Dashboard or Mobile
Use Case: Equipment Owner/Manager/Foreman (Future State)

Benefits

- Enhanced safety
- Avoided incidents/costs
- Preferred insurance rates
- Fleet management
- Theft protection

Dashboard App
Map of assets
Advanced threat detection
Push notifications
Custom project boundaries

How much will this technology cost?

Currently there is no cost to the end-user, and we will continue the program until the end of 2017.

The units are being designed to be low cost (<$500/unit).

Costs of current prototypes are promising.

Ultimately, the cost will depend on the commercialization partner.

But it's clear that keeping this technology low cost is key to adoption.
Why should you be excited about this technology?

- Safer Operations
- Avoided Incidents, Costs, and Delays
- Preferred Insurance Rates
- Differentiate from Competition
- Secondary Fleet Management
- Secondary Theft Protection