Energy Research and Development Division

FINAL PROJECT REPORT

Global Positioning System Excavation Encroachment Notification System Implementation

California Energy Commission

Edmund G. Brown Jr., Governor

June 2018 | CEC-500-2018-014

PREPARED BY:

Primary Author(s):
Khalid Farrag, Project Manager, GTI
Robert Marros, Principal Investigator, GTI
Jason Sphar, GTI
Steven Blitzstein, GTI

Gas Technology Institute (GTI)
1700 South Mount Prospect Road
Des Plaines, IL 60018
Phone: 847-768-0803 | Fax: 847-768-0501
http://www.gastechnology.org

Agreement Number: PIR-15-015

Prepared for:

California Energy Commission

Qing Tian, Ph.D., P.E.
Project Manager

Fernando Piña
Office Manager
ENERGY SYSTEMS RESEARCH OFFICE

Laurie ten Hope
Deputy Director
ENERGY RESEARCH AND DEVELOPMENT DIVISION

Drew Bohan
Executive Director

ACKNOWLEDGEMENTS

Gas Technology Institute expresses appreciation to Pacific Gas and Electric Company (PG&E) for providing technical and operational expertise in support of the development of the technology. We also thank PG&E and Southern California Gas Company (SoCal Gas) for deploying the system at their facilities to ensure research relevancy to the ratepayers of California. The authors acknowledge the support of the Technical Advisory Committee throughout the progress of this project.

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.

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- 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:

Farrag, Khalid; Marros, Robert; Sphar, Jason; Blitzstein, Steven; GTI (Gas Technology Institute). 2018. ***Global Positioning System Excavation Encroachment Notification System Implementation,*** Final Report. Publication number: CEC-500-2018-014.

TABLE OF CONTENTS

ACKNOWLEDGEMENTS i

PREFACE ii

ABSTRACT iii

TABLE OF CONTENTS iv

EXECUTIVE SUMMARY 1

Introduction 1

Project Purpose 2

Project Results 2

Project Benefits 3

CHAPTER 1: Introduction 5

1.1 Project Objectives 5

1.2 Report Structure 5

CHAPTER 2: System Components and Development 7

2.1 Hardware Technical Approach 7

2.2 Prototypes Components and Features 9

2.2.1 Prototype-1 9

2.2.2 Prototype-2 10

2.2.3 Prototype-3 11

2.2.4 Prototypes 4 and 5 11

2.3 Operations Dashboard 13

2.3.1 Utility's Dashboard 13

2.3.2 Establishing Utilities Geo-Fences 14

2.3.3 Operations Activities Metrics 17

CHAPTER 3: Installation and Data Management 20

3.1 Introduction 20

3.2 Data Management Architecture 21

3.3 Devices Installed at Utility Sites 22

3.4 Excavation Activities Monitoring ... 28
3.4.1 Activities Categories: ... 28
3.4.2 Data Collection from Equipment ... 29
3.5 Activity Recognition Algorithm ... 30
3.5.1 Activity Patterns for Excavation Equipment ... 31
3.5.2 Activity Patterns Algorithm ... 33
3.5.3 Activity Recognition Validation ... 34
3.6 Agricultural Equipment Activities Monitoring ... 35
CHAPTER 4: EEN System Deployment ... 39
4.1 System Installation and Operation at PG&E ... 39
4.2 Activities Recognition and Awareness ... 40
4.3 System Installation and Operation at SoCal Gas ... 46
CHAPTER 5: Evaluation of Project Benefits ... 49
5.1 Executive Summary of Cost Analysis Approach ... 49
5.2 Excavation Damage Cost Estimates ... 50
5.2.1 PHMSA Records of Excavation Damage to Gas Pipeline System in California ... 50
5.2.2 CBUC Records of Excavation Damage to Gas Pipeline System in California ... 57
5.2.3 CGA-DIRT Records of Excavation Damage to Gas Pipeline System in California 57
5.3 Technology Benefits Estimates ... 59
CHAPTER 6: Technology Transfer Activities ... 62
6.1 Situational Awareness Plan ... 62
6.1.1 Introduction ... 62
6.1.2 Common Operation Picture Layout ... 63
6.1.3 Organizations Roles ... 64
6.2 Technology Commercialization Efforts ... 65
6.2.1 Future Commercialization Plans ... 67
6.3 Technology Knowledge Transfer ... 68
GLOSSARY ... 69

REFERENCES **70**

APPENDIX A: Project Statements of Work **A-1**

APPENDIX B: Excavator Field Monitoring Report (Sample Record) **B-1**

APPENDIX C: Western Regional Gas Conference (Presentation) **C-1**

LIST OF FIGURES

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

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

Figure 3: Layout of the Device Incremental Development Procedure 7

Figure 4: Communication Loop for the Prototype Development 8

Figure 5: View of Prototype 1-A of the Device Hardware 9

Figure 6: View of Prototype 1-B of the Device Hardware 10

Figure 7: View of Prototype 2 of the Device Hardware 10

Figure 8: View of Prototype 3 of the Device Hardware 11

Figure 9: View of Prototype 5 of the Device Hardware 12

Figure 10: Operations Dashboard Displaying Map of the Utility Pipeline 14

Figure 11: Devices Attributes in the Operations Dashboard 15

Figure 12: Operations Dashboard Displaying Geo-Fence Added by User 16

Figure 13: Operations Dashboard with Geo-Fences for Various Pipe Sizes 16

Figure 14: Metrics Dashboard for Devices Performance 17

Figure 15: Metrics Dashboard of Most and Least Active Equipment 18

Figure 16: Activities Metrics for Excavation Contractors 18

Figure 17: Dashboard Showing Areas of Concentration for Excavator Activity 19

Figure 18: Example of the Data Transferred from the GPS EEN Device 20

Figure 19: System Architecture to Capture and Process Sensors Data 21

Figure 20: Placement of the GPS EEN Unit in the Excavator 23

Figure 21: Time Plot of the Observations and Accelerometer Data 25

Figure 22: Time Plot of the Observations and Orientation Data 26

Figure 23: Time Plot of the Gyro Data from Excavator 27

Figure 24: Observations by Activities for Backhoe Equipment 30

Figure 25: Observations by Activity Categories for Excavator Equipment....................................30
Figure 26: Acceleration, Orientation, and Gyroscope for 'Idle' Backhoe Activity..........................31
Figure 27: Acceleration, Orientation, and Gyroscope for 'Digging' Backhoe Activity 32
Figure 28: Acceleration, Orientation, and Gyroscope for 'Driving' Backhoe Activity..................33
Figure 29: Machine Learning Algorithm Training and Prediction Process....................................34
Figure 30: Absolute Accuracy Data of the Excavation Activities...35
Figure 31: Relative Accuracy Data for Each of the Excavation Activities.......................................35
Figure 32: Observations for Agricultural Digging Activity 36
Figure 33: Observations for Agricultural Idle activity...37
Figure 34: Statistical Average of Agricultural Equipment Speed 38
Figure 35: Installation of the GPS EEN Unit in the Excavator...39
Figure 36: Historical Excavation Data in the Dashboard 40
Figure 37: Digging Activities for a Specified Data Range 43
Figure 38: Attributes of the Data Collection Point 44
Figure 39: 'Query' Tool for Device and Date Search..44
Figure 40: Results of the 'Query' Tool...45
Figure 41: Results of the 'Select' Tool..45
Figure 42: EEN Device Installation on a Utility Backhoe 46
Figure 43: EEN Device Registration Form..47
Figure 44: Sample Email Message of Device inside a Primary Boundary 47
Figure 45: Equipment Location Records in the Historical Web Application 48
Figure 46: Reported Gas Service Safety Incidents in California by Threats 57
Figure 47: Excavation Damage Data in California in 2016...59
Figure 48: Excavation Damage by Equipment Type in California, 2016...59
Figure 49: Organizations Roles in Information Flow Chart...64
Figure 50: Market Share for Hydraulic Excavators 65

LIST OF TABLES

Table 1: Design Features of the GPS EEN Prototypes 8
Table 2: Design Features of Prototype 5 Hardware 13
Table 3: Data Format Transferred from the Hardware Device 22
Table 4: Sample Field Observation of Activities 28
Table 5: Details of Datasets Used in Machine Learning 29
Table 6: Data Observation Form for Backhoes During Field Work 41
Table 7: Data Observation Form for Excavators during Field Work 42
Table 8: Excavation Damage by Root Cause in California Gas Distribution in 2016 51
Table 9: Average Annual Costs from PHMSA Significant Excavation Incidents 52
Table 10: Consequences of Significant Incidents in Gas Transmission System 2010 – 2016 53
Table 11: Root Causes of Significant Incidents in Gas Transmission System 2010 – 2016 54
Table 12: Consequences of Significant Incidents in Gas Distribution System 2010 – 2016 55
Table 13: Common Deficiencies Listed in Pipeline Incidents 1994-2011 62
Table 14: Selected GPS/Telematic Commercializers 66
Table 15: List of Conferences and Technology Presentations 68

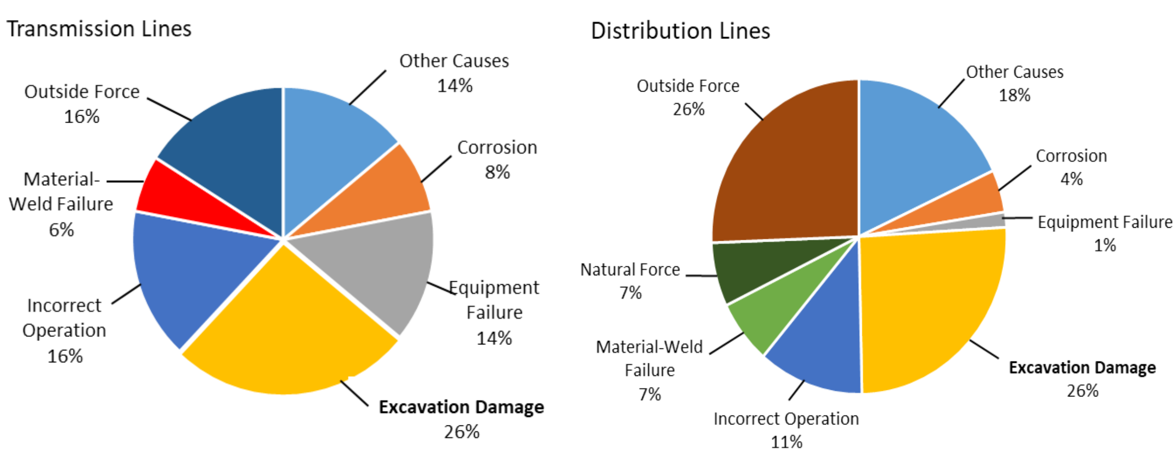
EXECUTIVE SUMMARY

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)



Source: PHMSA, National Pipeline Performance Measures, https://www.phmsa.dot.gov/data-and-statistics/pipeline/national-pipeline-performance-measures

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[1] Pipeline and Hazardous Materials Safety Administration (PHMSA), U.S. DOT https://www.phmsa.dot.gov/data-and-statistics/pipeline/distribution-transmission-gathering-lng-and-liquid-annual-data

[2] Common Ground Alliance (CGA) http://commongroundalliance.com/dirt-2016-interactive-report

Project Purpose

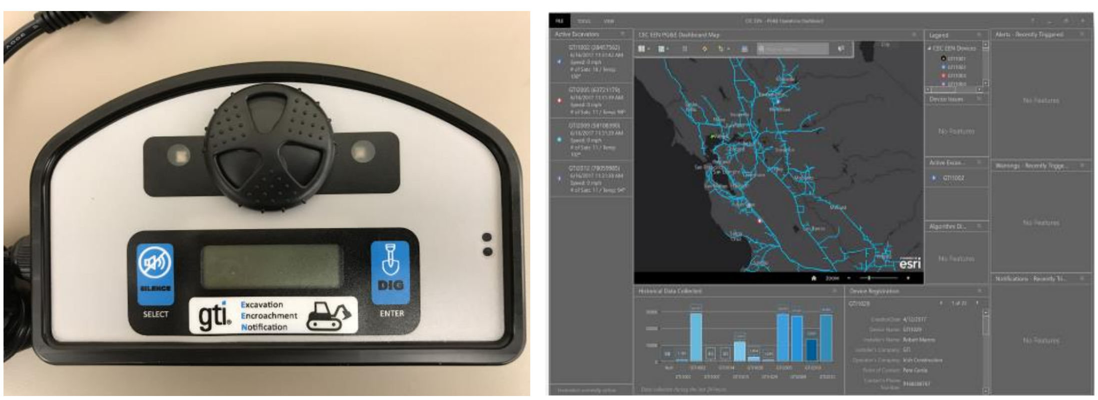
To help address excavation damage in the field, this project designed, developed, and tested a Global Positioning System (GPS) Excavation Encroachment Notification System. The project objectives included:

- 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



A B

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.

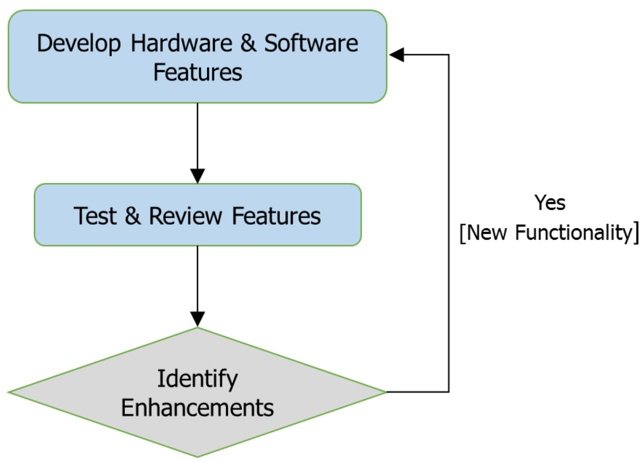
- Chapter 4: System Deployment. This chapter presents the installation and monitoring of the hardware at the utilities territories.
- Chapter 5: Evaluation of Project Benefits and Cost Analysis.
- Chapter 6: Technology Transfer Plan. This chapter addresses the development of situational awareness approach 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



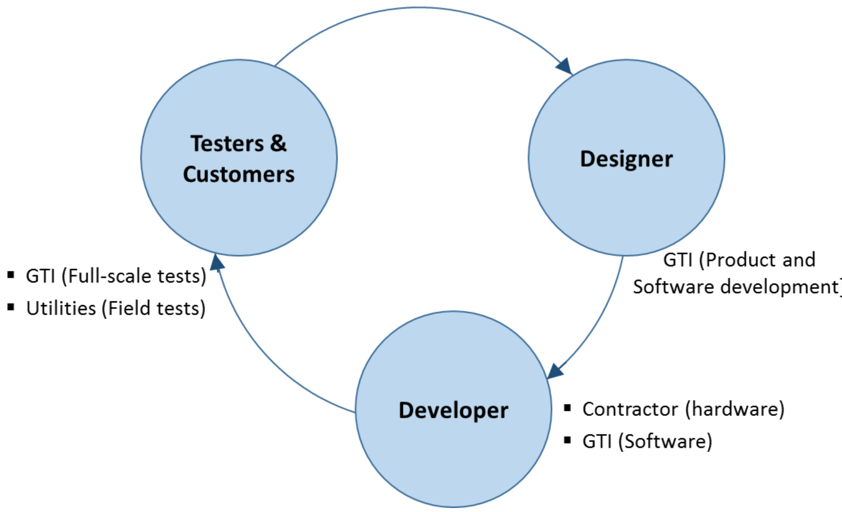
Source: Gas Technology Institute

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



Source: Gas Technology Institute

Table 1: Design Features of the GPS EEN Prototypes

Features	Prototype Version					
	1-A	1-B	2	3	4	5
Hardware						
Board Type: - Development Board	X	X				
- Commercial Board			X	X	X	X
Battery Backup		X				
Hard-wired to equipment					X	X
Antenna: - Separate	X					
- Integrated		X	X			
- Integrated, oriented				X	X	X
Display Screen [Modified in each prototype]			X	X	X	X
Buttons Input				X	X	X
Light Signals [Improved in each prototype]				X	X	X
Sound Signals [Improved in each prototype]				X	X	X
Water Proof Case				X	X	X
Software						
1-way Communication signal	X	X	X			
2-way signal [Operator feedback]				X	X	X
Activities Identification Algorithm						X
Data stream rate - 5 sec	X	X	X	X	X	
- Variable, 1-hour at idle						X

Display Error messages					X	X
Web upgrade installation and setup					X	X

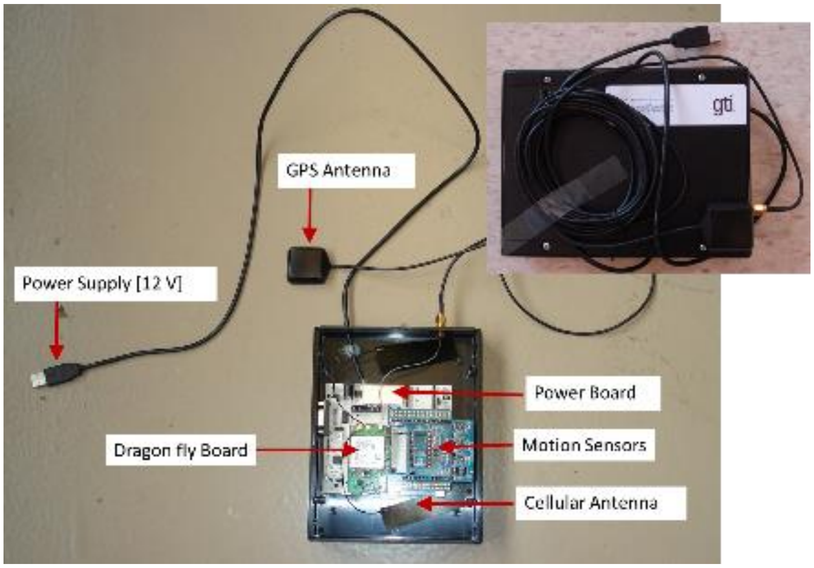
Source: Gas Technology Institute

2.2 Prototypes Components and Features

2.2.1 Prototype-1

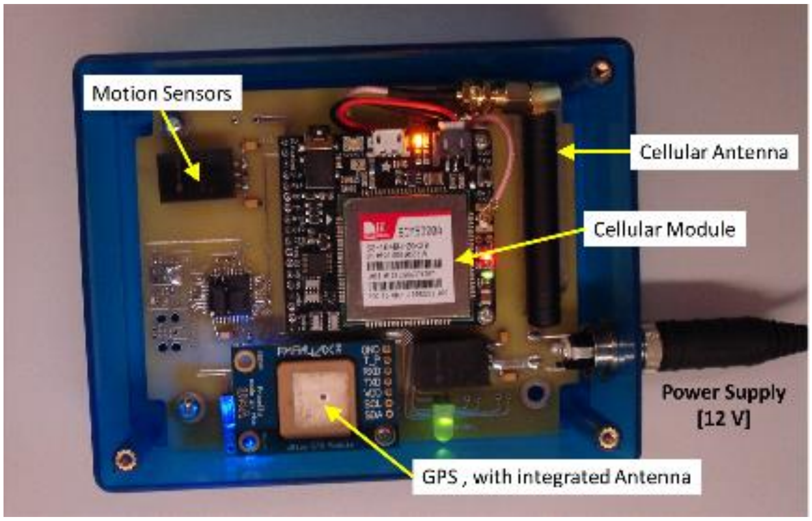
Two versions of this prototype were built. Prototype 1-A was built at Gas Technology Institute (GTI) and consisted of the GPS unit, cellular unit and antenna, motion sensors, and power board (Figure 5). The unit had an outside GPS antenna. Prototype 1-B was built by a vendor and included an internal 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

Figure 6: View of Prototype 1-B 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.

Figure 7: View of Prototype 2 of the Device Hardware

Source: Gas Technology Institute

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

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

Source: Gas Technology Institute

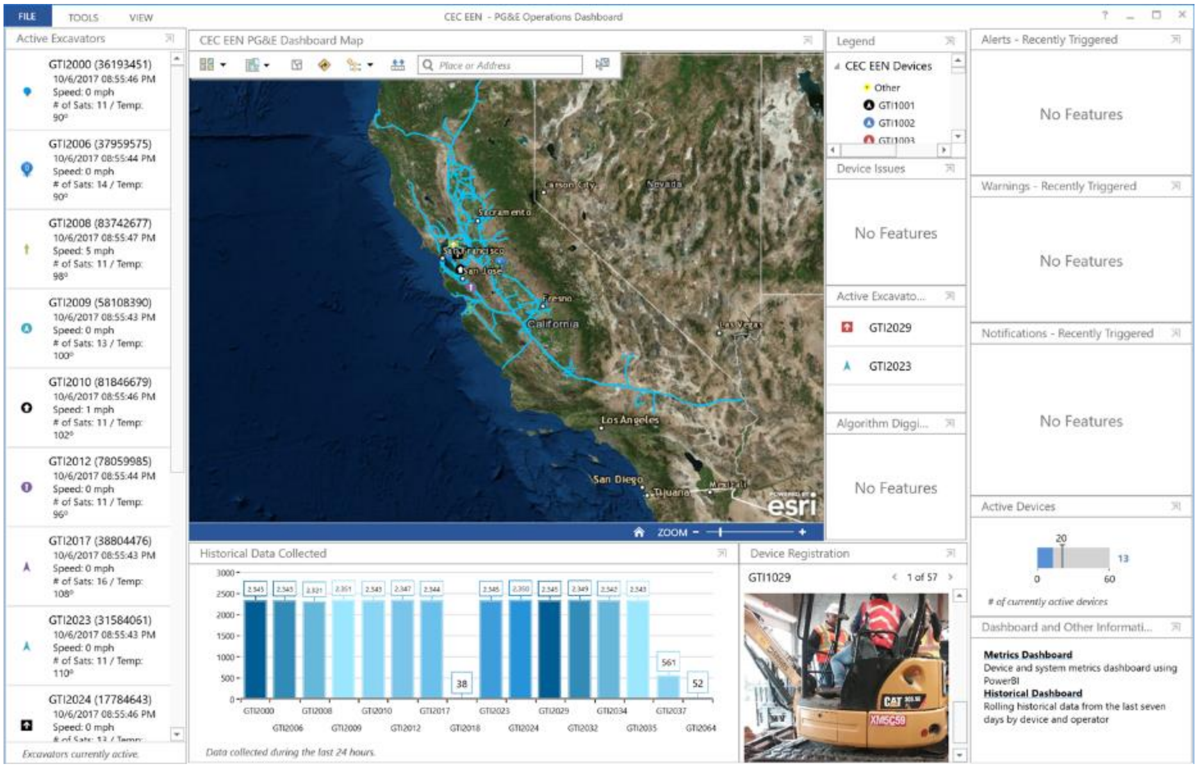
2.3 Operations Dashboard

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



Source: Gas Technology Institute

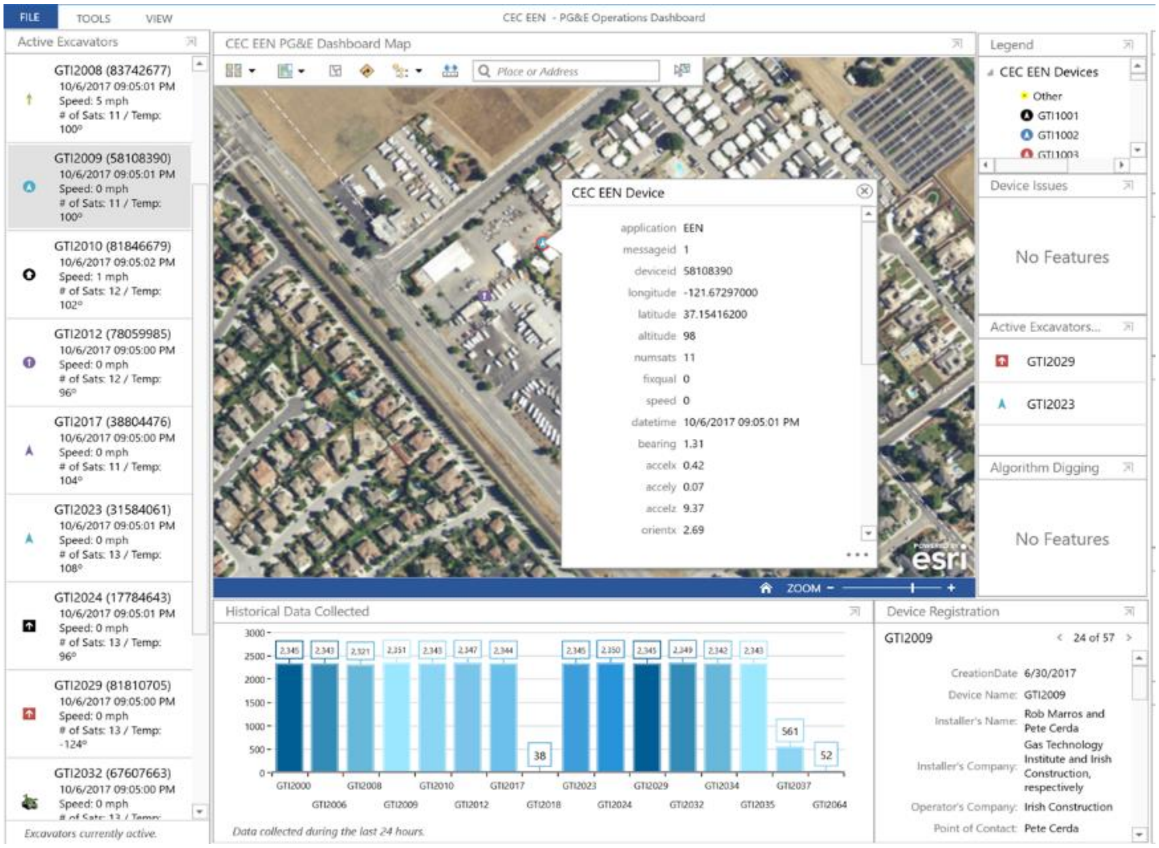
Details of the equipment attributes transmitted from the EEN devices are linked to each excavator in the dashboard. The user displays these attributes by clicking on the device in the active excavators list, or on its representative icon on the map. Figure 11 shows a screenshot of a live view in the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

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

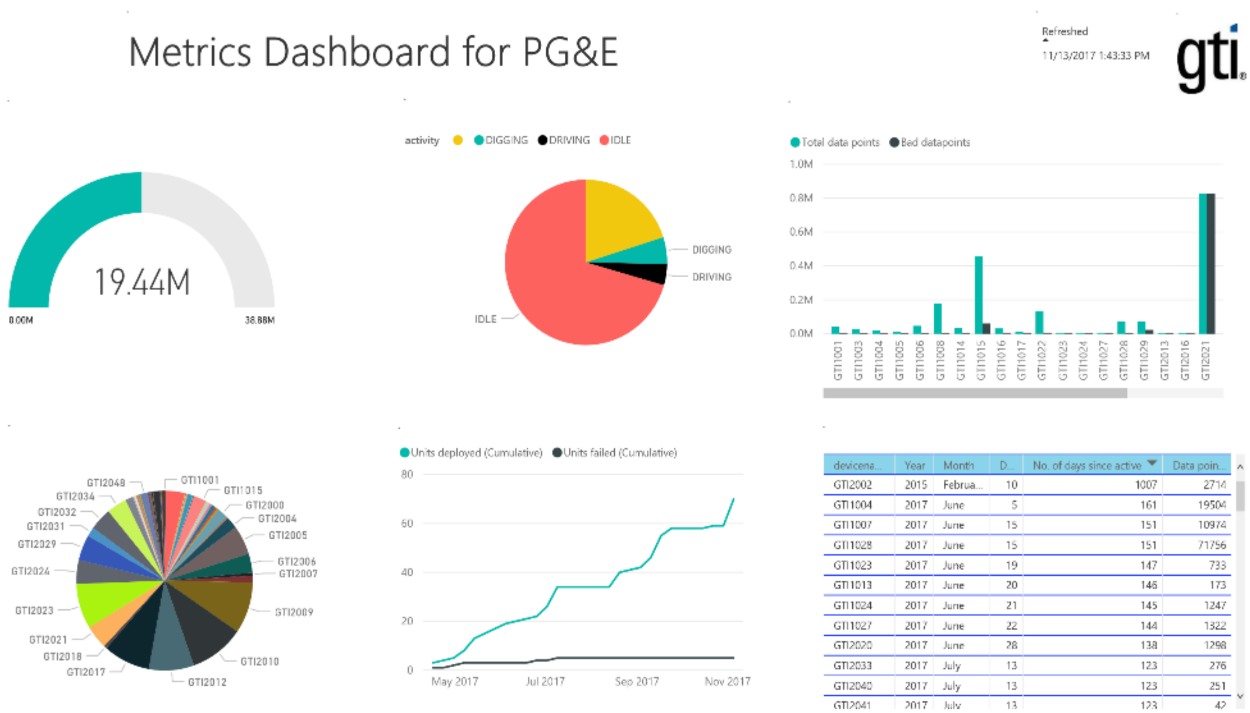
Source: Gas Technology Institute

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

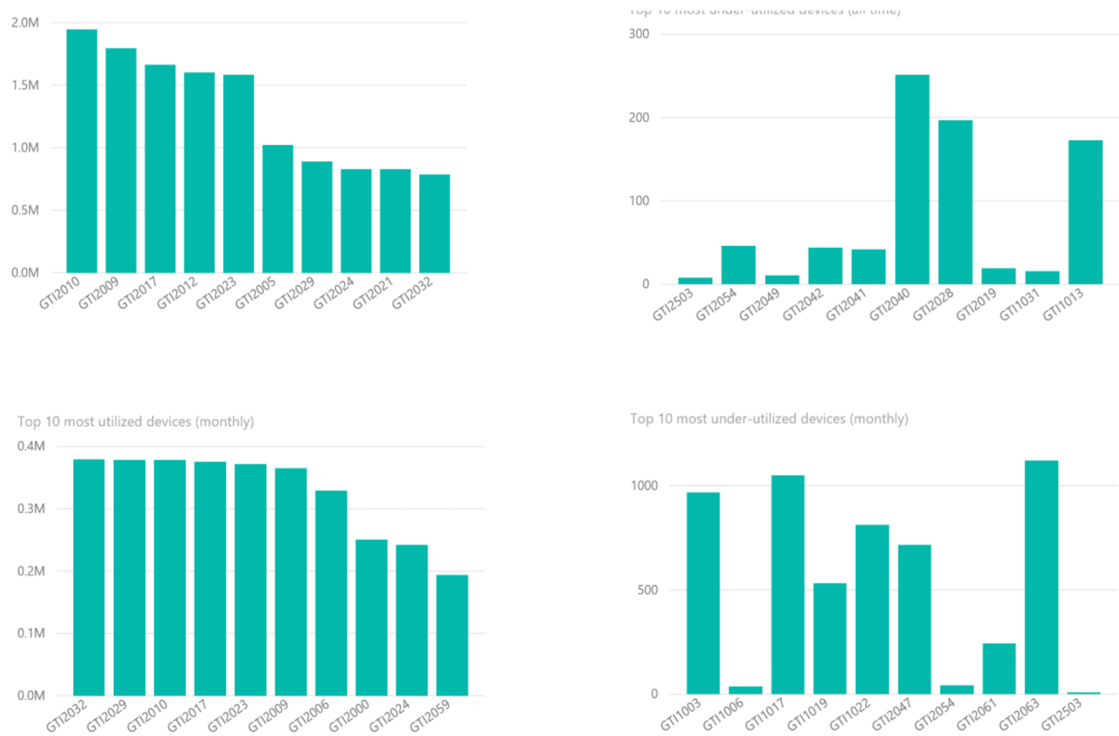


Source: Gas Technology Institute

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.

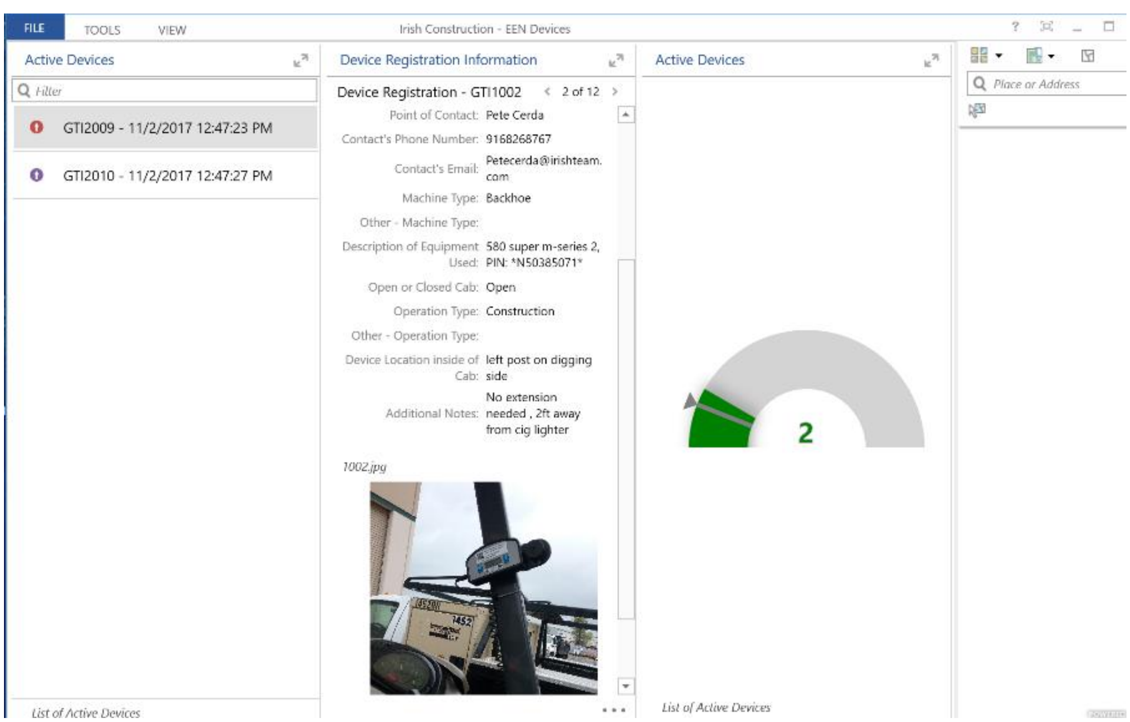
The metrics board in Figure 16 provides equipment information specific to individual owners containing the operations data of their equipment, plus statistical analysis of their activities. The metrics display all active equipment, their registration information, and a map showing their locations.

Figure 15: Metrics Dashboard of Most and Least Active Equipment



Source: Gas Technology Institute

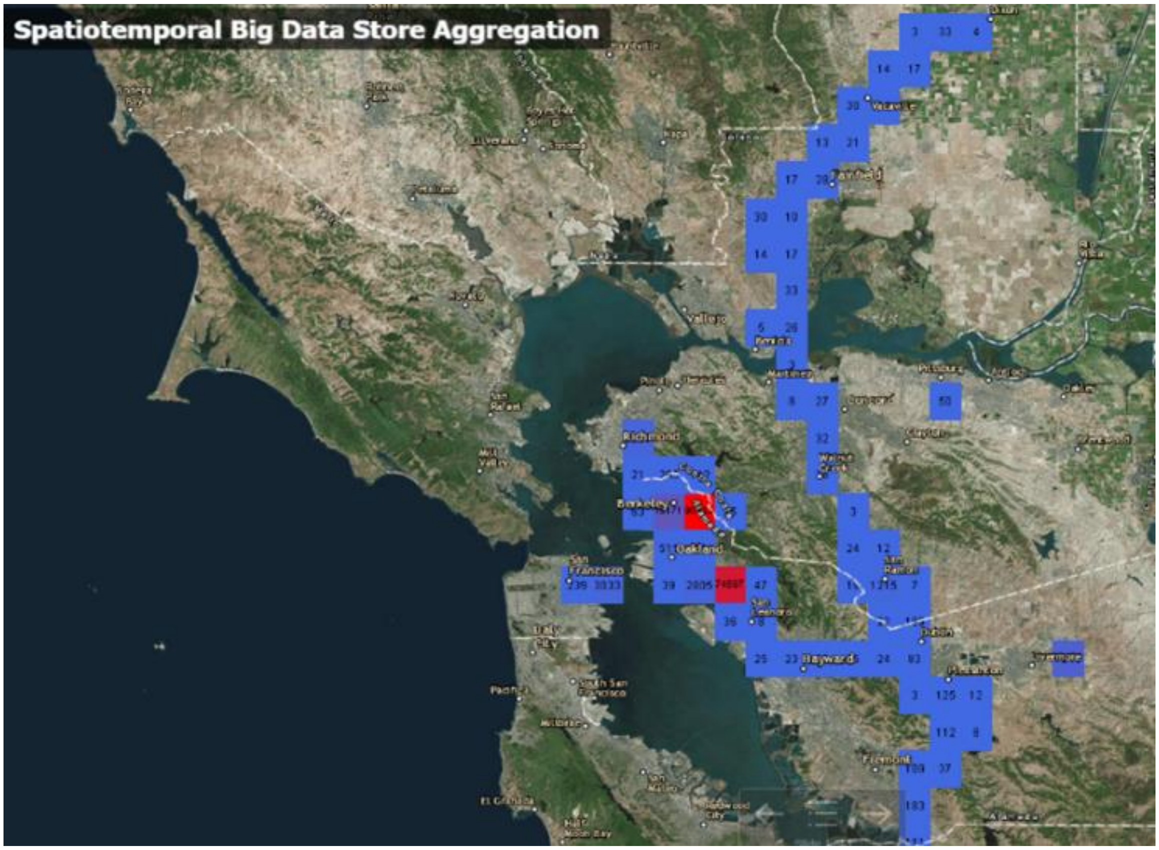
Figure 16: Activities Metrics for Excavation Contractors



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:

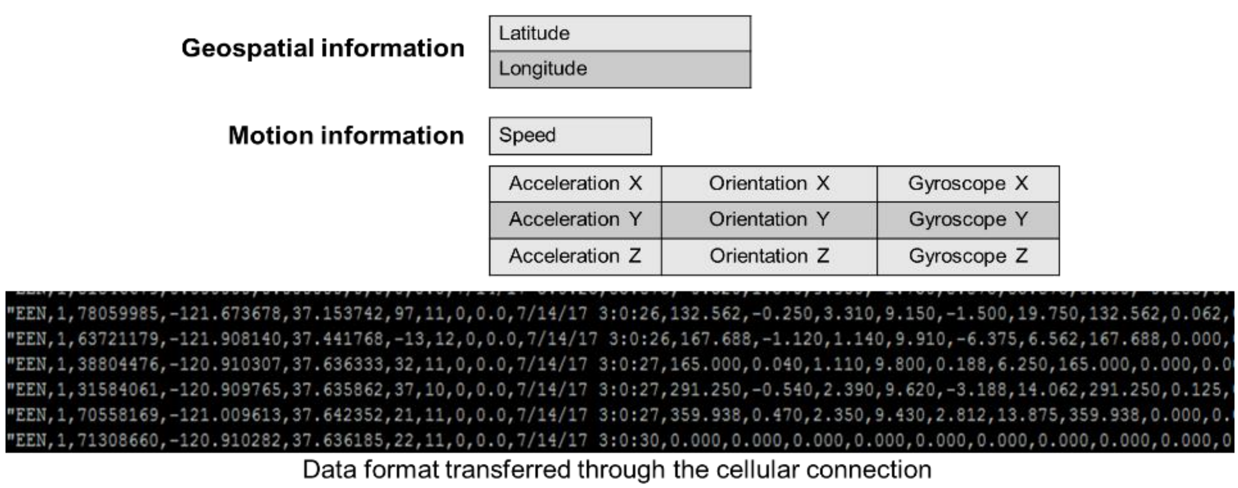
- The GPS location of the equipment and equipment's speed
- Equipment's nine-degree of freedom motion activities; consisting of its acceleration, gyro, and orientation in the x, y, and z directions
- Other status information including device ID, date, time, temperature, and cellular signal condition.

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



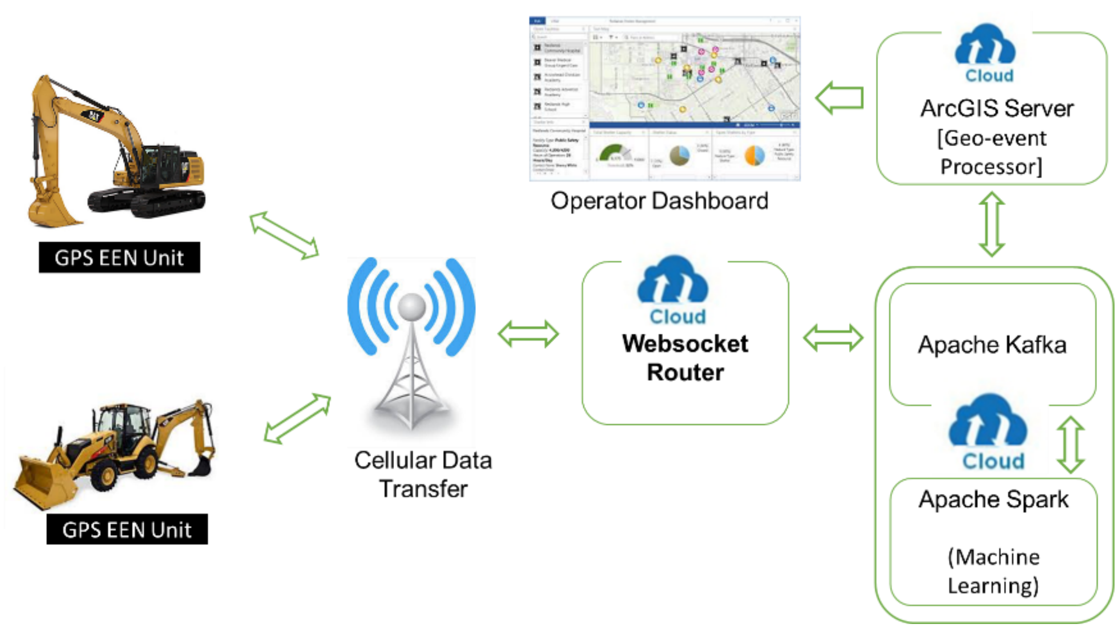
Source: Gas Technology Institute

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

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

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.

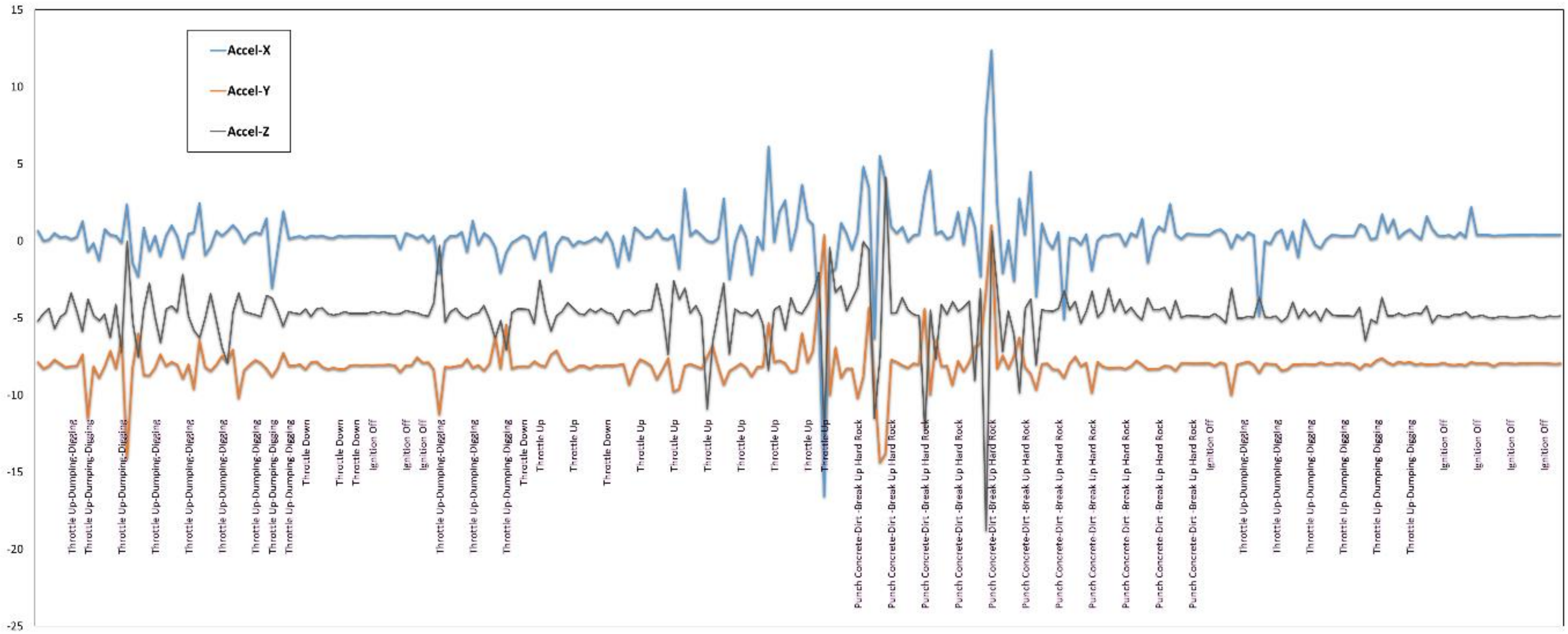
Figure 20: Placement of the GPS EEN Unit in the Excavator

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.

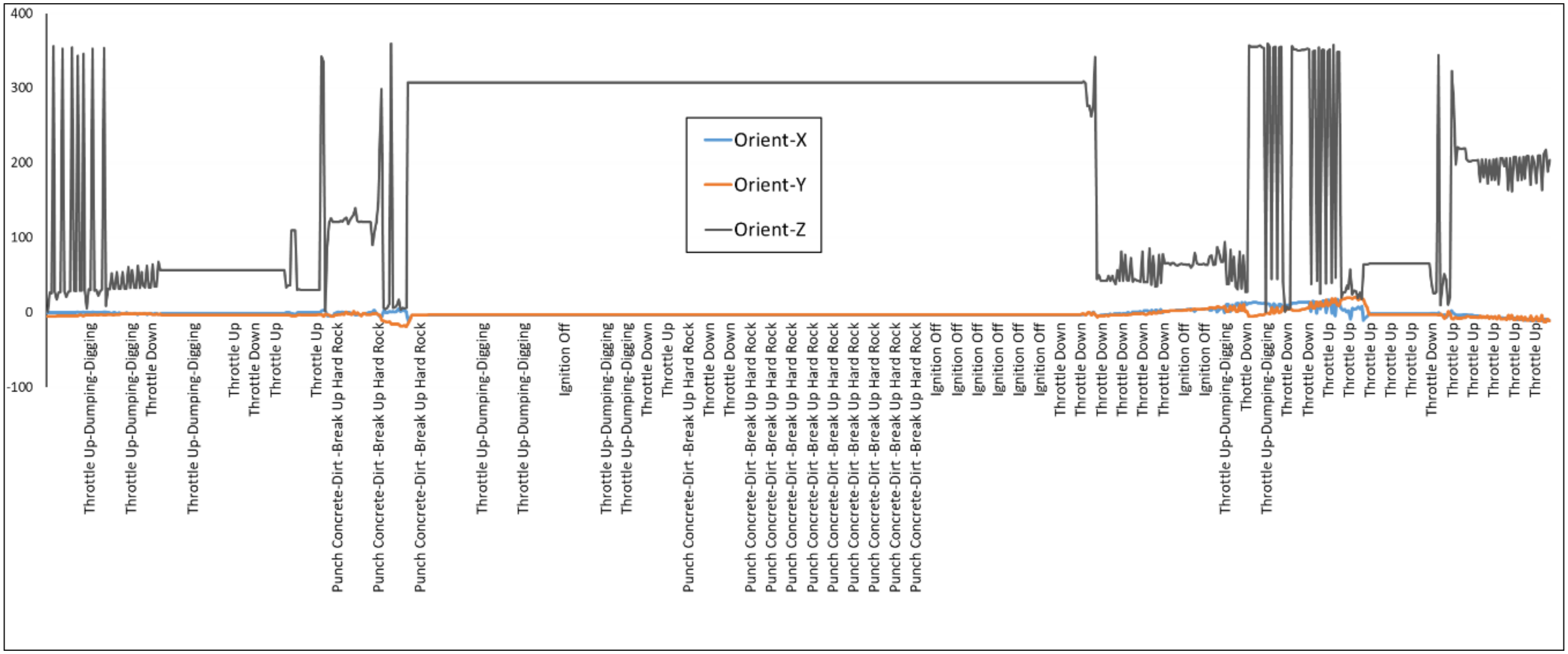
The data was extracted from the server and analyzed. Sample graphs from the hardware sensors for various excavator activities are shown in Figures 21 to 23 for the acceleration, orientation, and gyro data, respectively. The figures show the correlations between the sensors data and the observed excavators 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



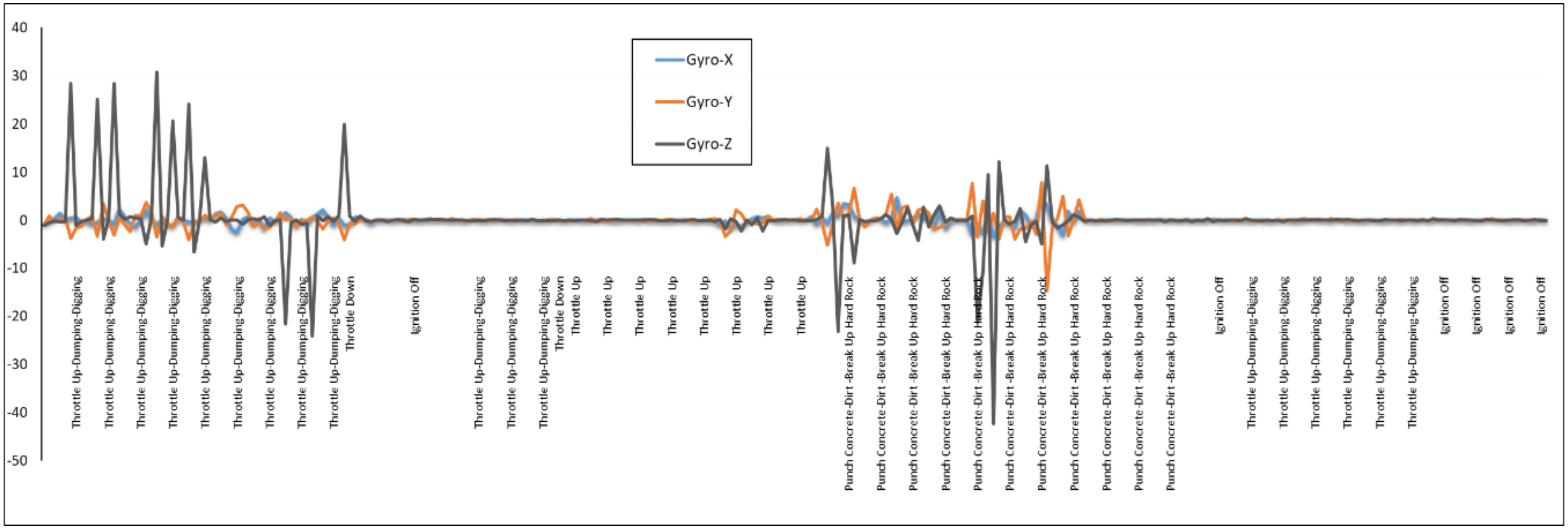
Source: Gas Technology Institute

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

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

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.

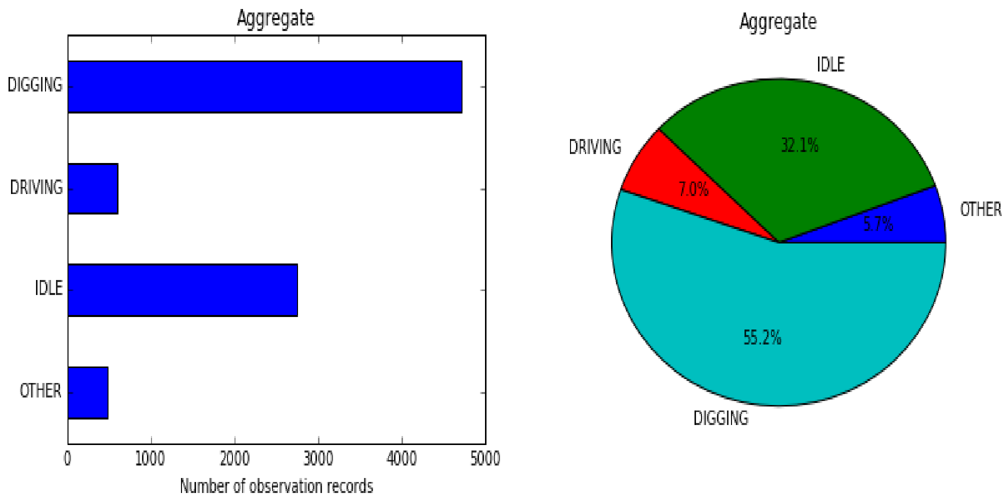
Figures 24 and 25 show the distribution of observation records by activities for backhoe and excavators, respectively. The most frequent records were collected for 'Digging' activity.

Table 5: Details of Datasets Used in Machine Learning

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

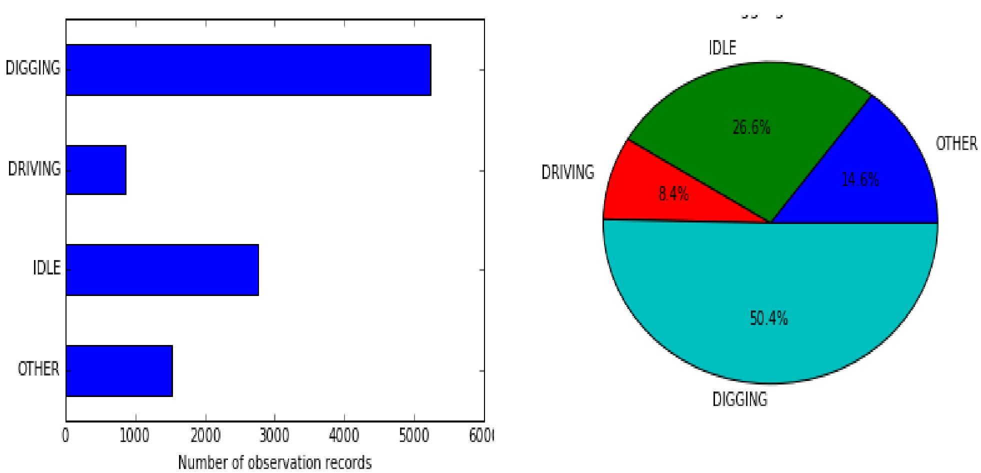
Source: Gas Technology Institute

Figure 24: Observations by Activities for Backhoe Equipment



Source: Gas Technology Institute

Figure 25: Observations by Activity Categories for Excavator Equipment



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:

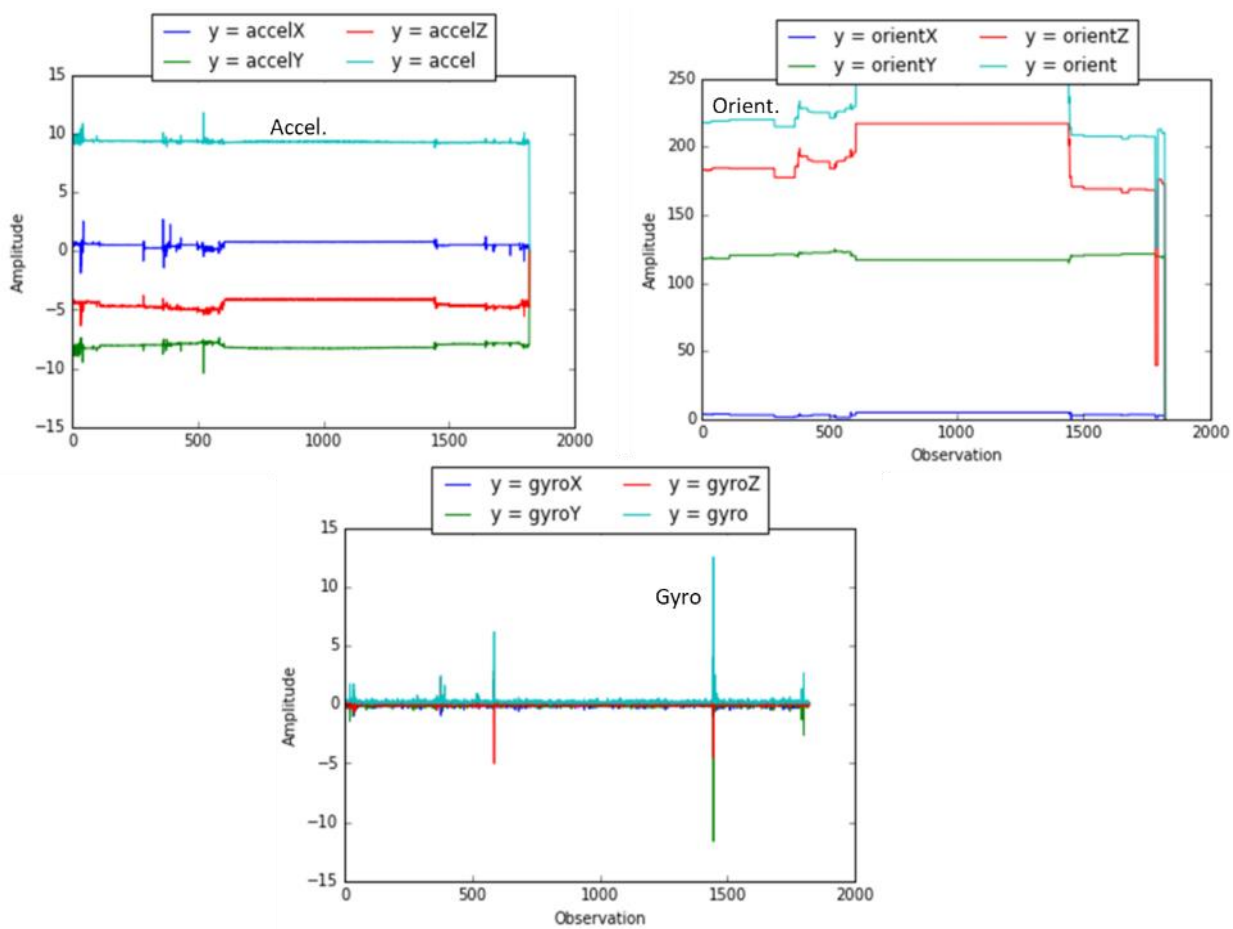
- Acceleration $a = \sqrt{ax^2 + ay^2 + az^2}$
- Gyro $g = \sqrt{gx^2 + gy^2 + gz^2}$
- Orientation $o = \sqrt{ox^2 + oy^2 + oz^2}$

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 [3].

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.

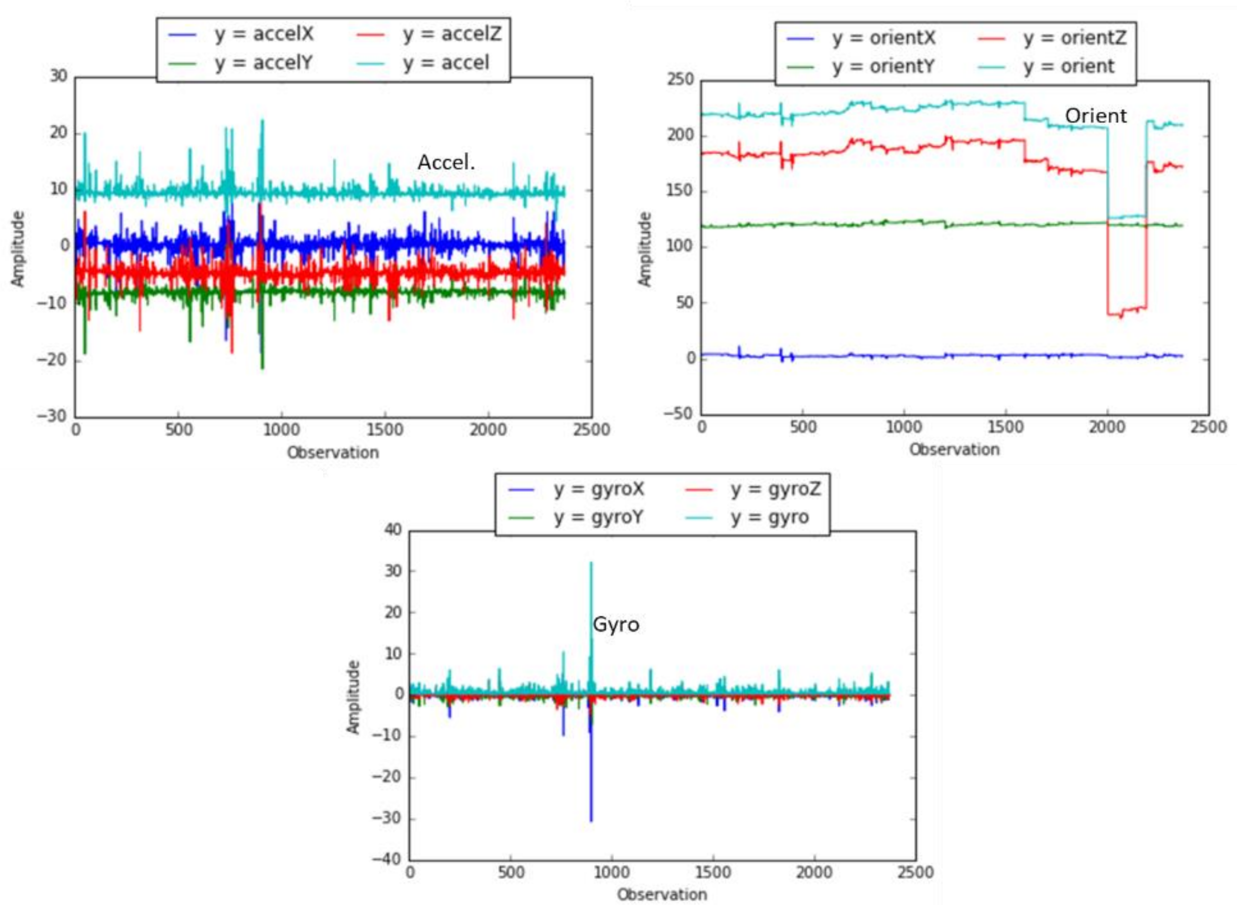
Figure 26: Acceleration, Orientation, and Gyroscope for 'Idle' Backhoe Activity



Source: Gas Technology Institute

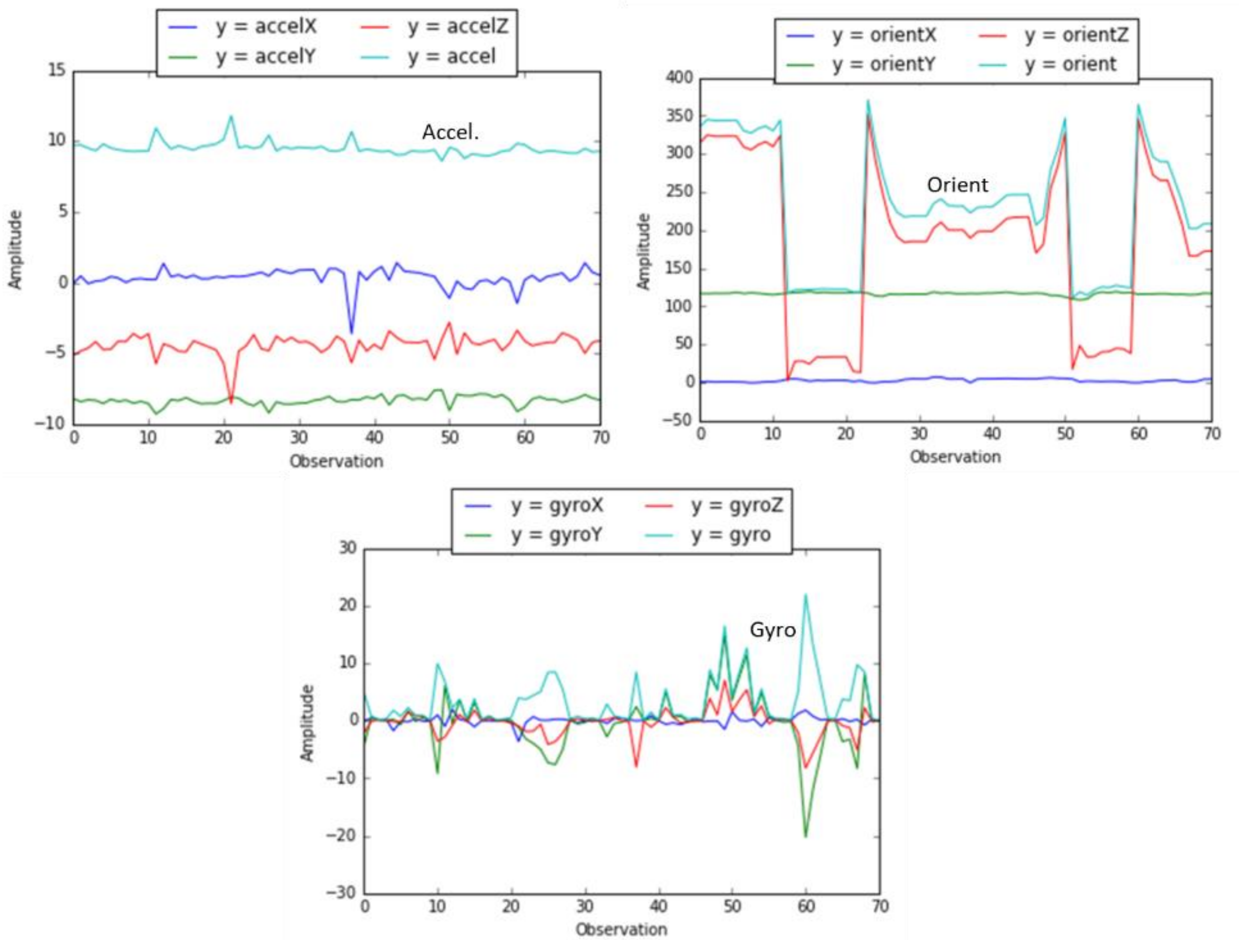
[3] Farrag, Khalid; Marros, Robert; Sphar, Jason; Blitzstein, Steven; GTI (Gas Technology Institute). 2017. GPS Excavation Encroachment Notification System (GPS EENS), Installation Planning. Publication number: CEC-500-2018-xxx

Figure 27: Acceleration, Orientation, and Gyroscope for Digging Backhoe Activity



Source: Gas Technology Institute

Figure 28: Acceleration, Orientation, and Gyroscope for Driving Backhoe Activity



Source: Gas Technology Institute

3.5.2 Activity Patterns Algorithm

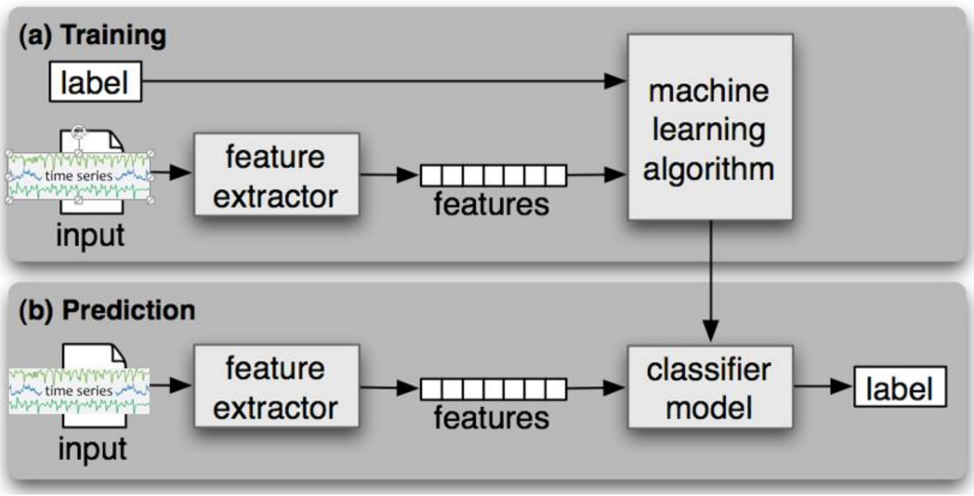
The data shown in the previous section were passed through a filter to remove any noise or outliers. The noise filter is a 7-point smoothing function which calculates each point to the average of its six nearest neighbors around the point.

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



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 = $tp\ /\ (tp + fp)$

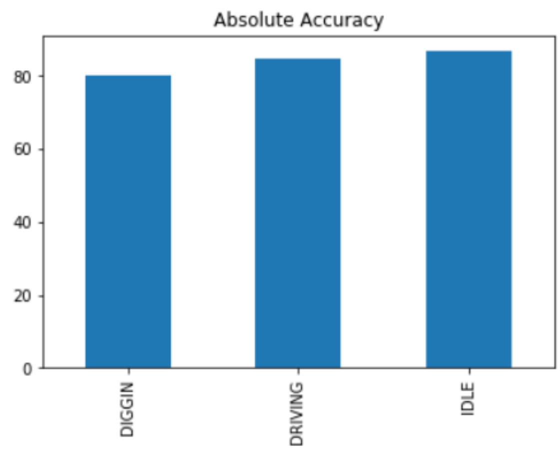
Recall/Sensitivity = $tp\ /\ (tp + fn)$

Specificity = $tn\ /\ (tn + fp)$

Accuracy = $tp\ /\ (tp + fp)$

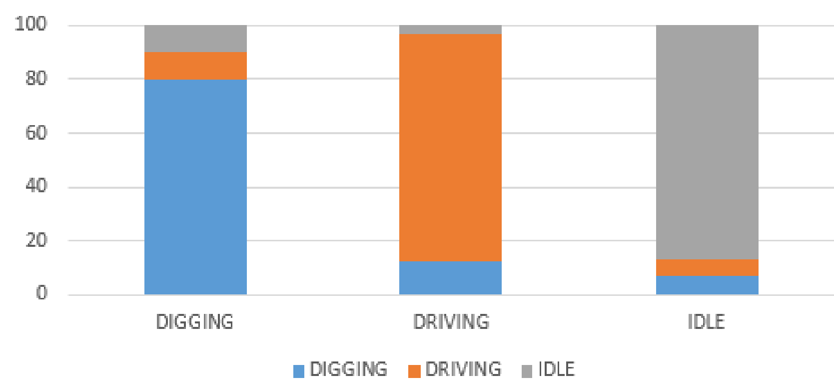
For the validation, four datasets were used to calculate and plot the accuracy metrics for the three activities. Figures 30 and 31 show the absolute and relative accuracy results. The accuracy percentages for idle, digging, and driving activities were 87 percent, 80 percent, and 85 percent, respectively.

Figure 30: Absolute Accuracy Data of the Excavation Activities



Source: Gas Technology Institute

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



Source: Gas Technology Institute

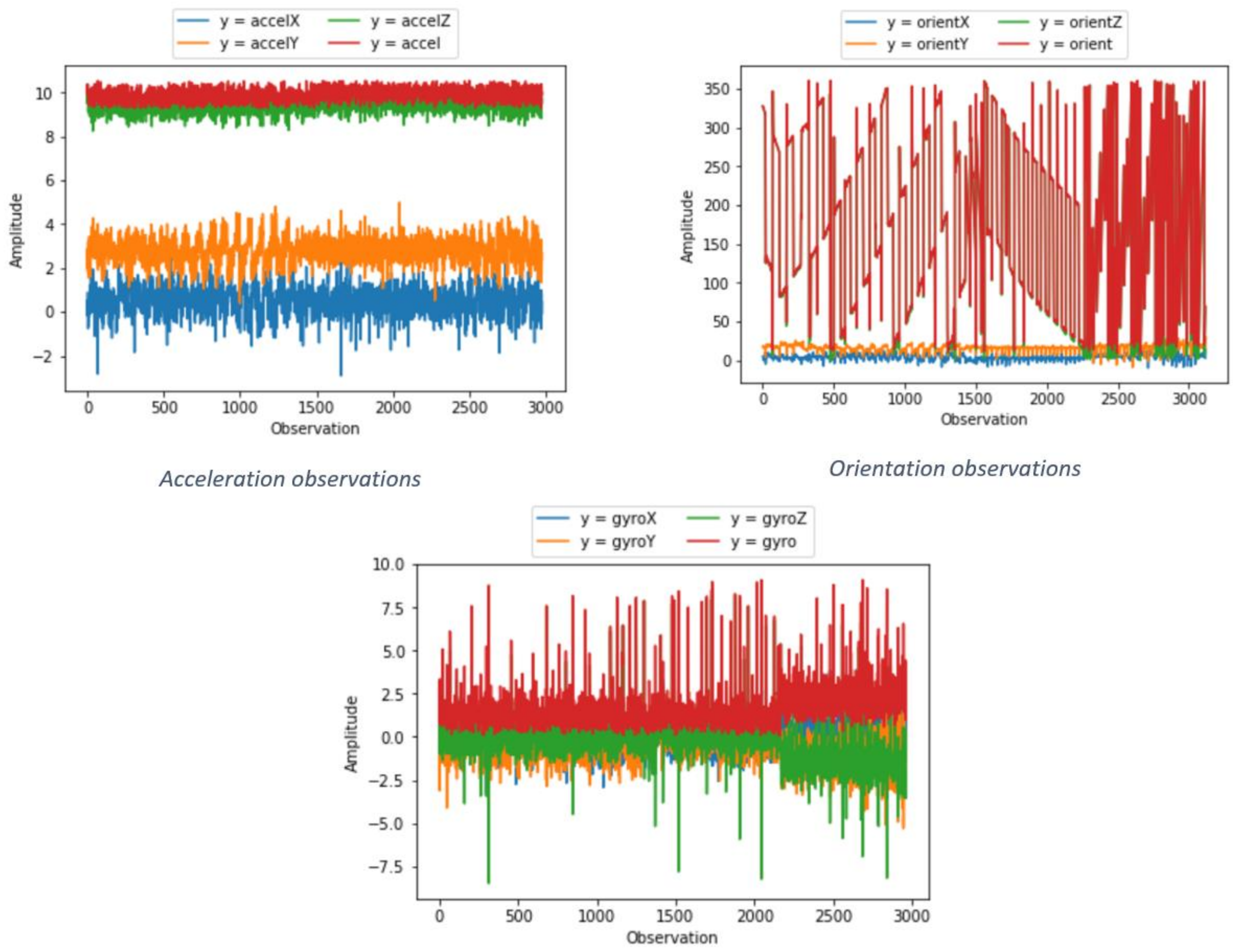
3.6 Agricultural Equipment Activities Monitoring

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



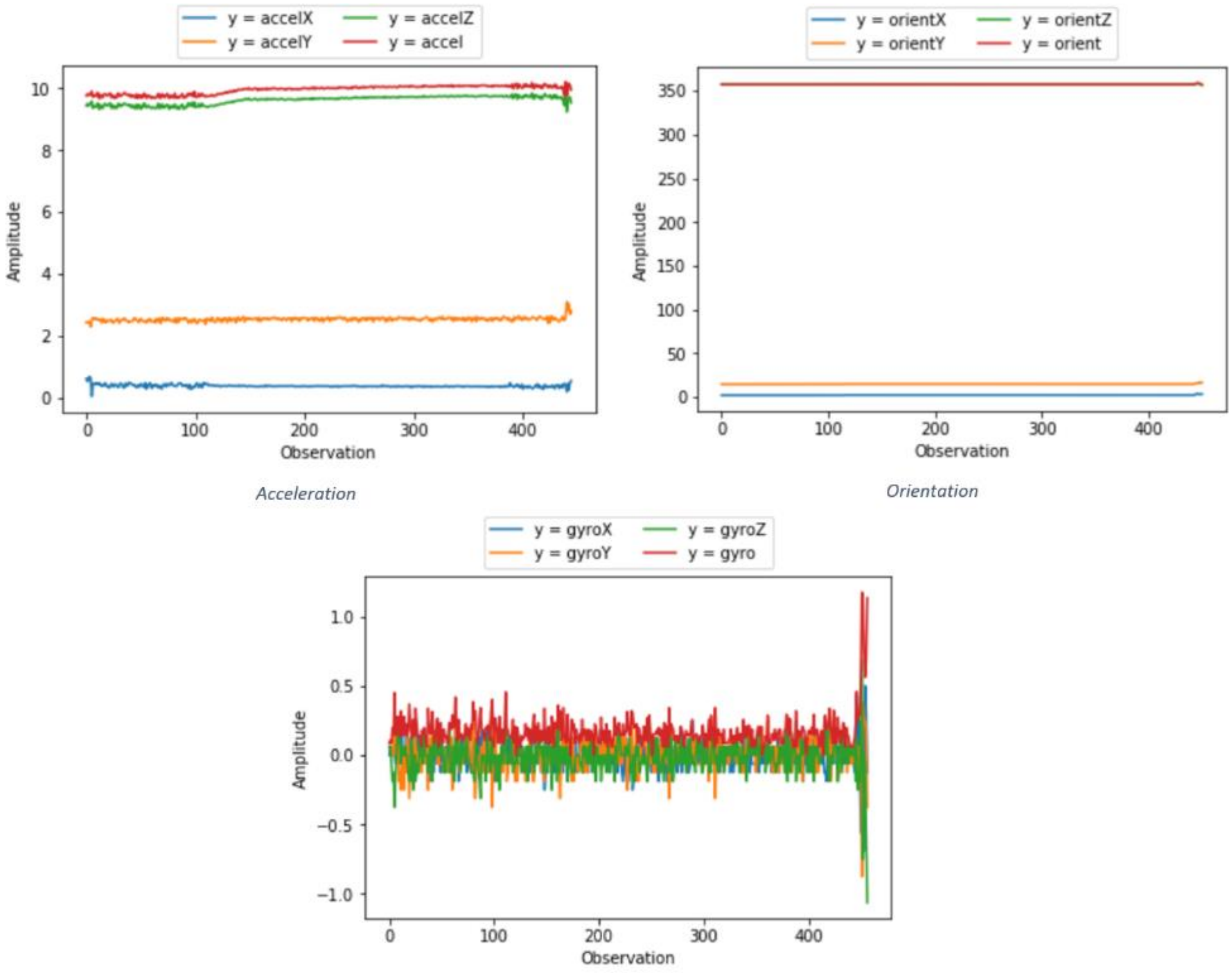
Acceleration observations

Orientation observations

Gyroscope observations

Source: Gas Technology Institute

Figure 33: Observations for Agricultural Idle Activity



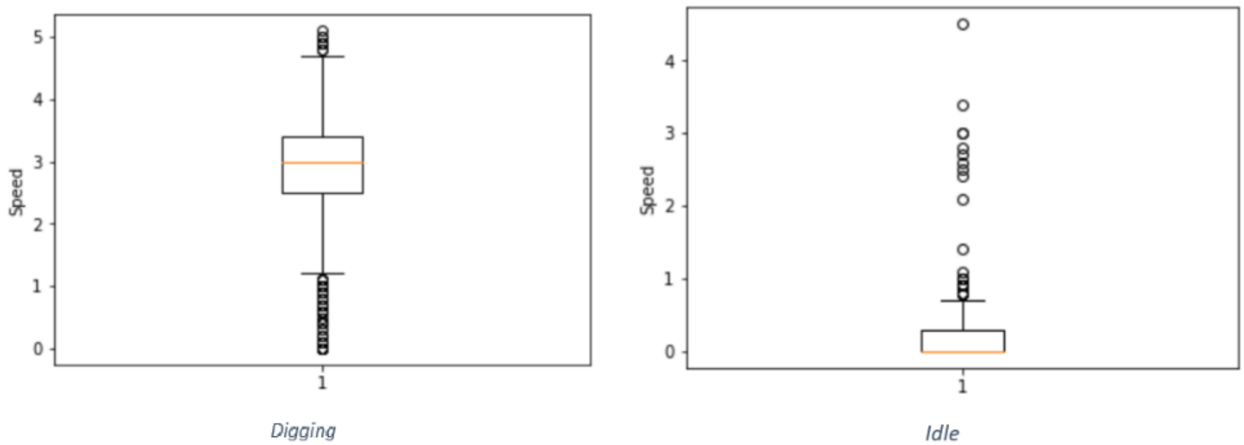
Acceleration

Orientation

Gyroscope

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 requireded.

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

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.

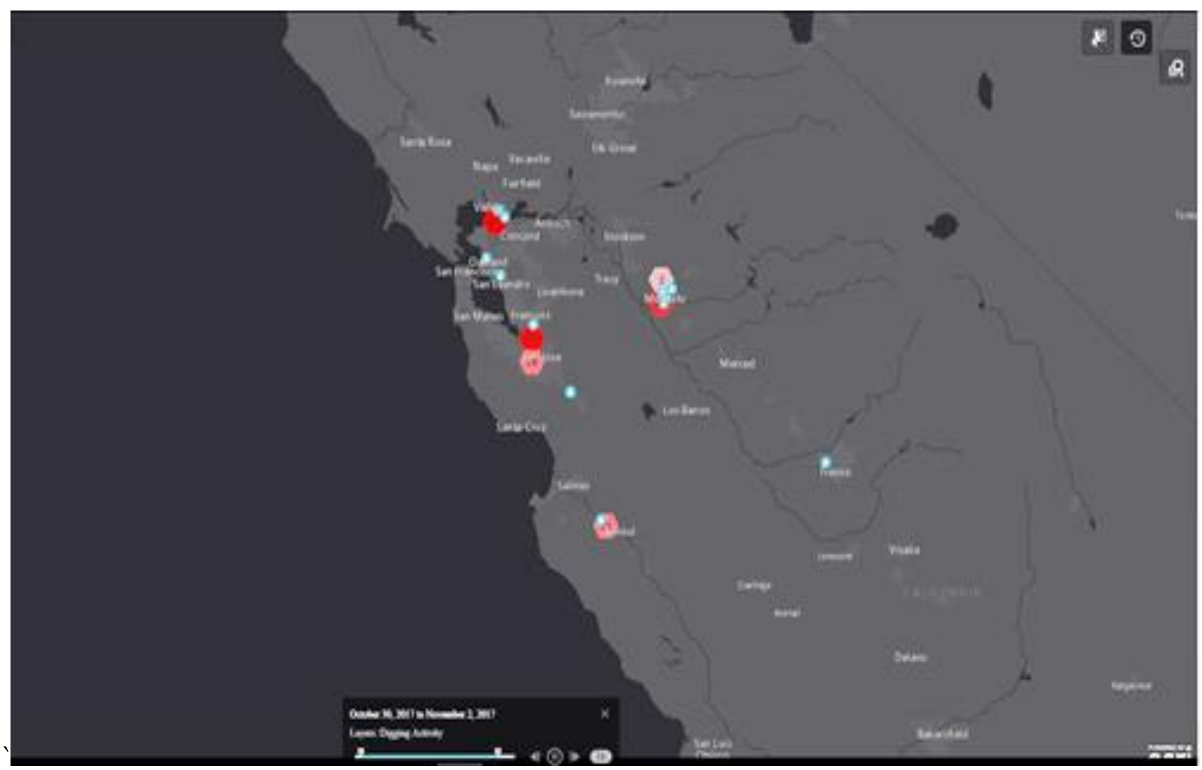
4.2 Activities Recognition and Awareness

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.

Figure 36: Historical Excavation Data in the Dashboard



Source: Gas Technology Institute

Table 6: Data Observation Form for Backhoes During Field Work

GTI Excavator Testing

Project Number		Excavator Operator	Bill Mulligan	Date	30-Mar-17
PI		Excavator Make	John Deere	Time	
PM		Excavator Model	310J Backhoe	Test #	
Data Recorder	David Feliciano	Notes		Weather conditions	
Devices		Test Location		Temperature	

Test #	Activity	Sub-activity	Description and Timing	Outrigging Deployed	Time Start	Time End	Notes
1	**Idle**						
1A		low/regular	4 minutes at __900______ RPMs	☐	1228	1232	
1B		high	4 minutes at ____2400____ RPMs	☐	1232	1236	This is the RPM at which digging would take place.
2	**Driving**			N/A			
2A		On gravel drive	7 minutes total, drive 3.5 minutes pause 20 seconds and repeat. Drive at ______ mph.	N/A	1238	1245	4.5 minutes going slow (2nd gear) rest of time fast (3rd gear)
2B		Varying speeds	4 minutes total, drive 1 minutes pause 20 seconds and repeat three times. Start at lowest speed and accelerate to highest safe speed.	N/A	1246	1250	Travelled in same loop as test 2A, drove at random variable speeds.
3	**Stopping**	drive 20 ft, stop, reverse, stop	4 minutes total	☐	1251	1255	
4	**Stationary**			☐			
4A		Rotating cabin 360 degrees (excavator only)	Three rotations total, pause 20 seconds before repeating action.	☐			SKIP
4B		Slow in 45 deg increments (excavator only)	3 minutes total, pause 20 seconds before repeating action.	☐			SKIP
4C		While digging	4 minutes total. Pick up earth and drop, do not move dirt to another location.	☒	1256	100	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.
4D		Extend arm and back	3 minutes total, pause 30 seconds before repeating action.	☒	102	105	Cab barely moves. I don't think Dig was pressed.
5	**Extend arm while excavating**			☒	107		The backhoe executed a repositioning manuever.
5A		Dig, pickup, move, drop	5 minutes total.	☒	109	114	Dig was pressed during this.
6	**Moving and dragging equipment/dirt**		3 minutes total	☐			SKIP
7	**Backfill**	(Backhoe only)	10 minutes total	☐	117	122	To backfill the backhoe uses the bucket on the front of the equipment and drives around.
8	**Deploy Outrigging**	(Backhoe only)	2 minutes total, pause 10 seconds before repeating action. Repeat deploying and retracting outrigging.	☐	124	126	
9	**Obsticle Course**		35-40 minutes total. Dig a __5_x_5__ 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).	☒	127		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

Source: Gas Technology Institute

Table 7: Data Observation Form for Excavators during Field Work

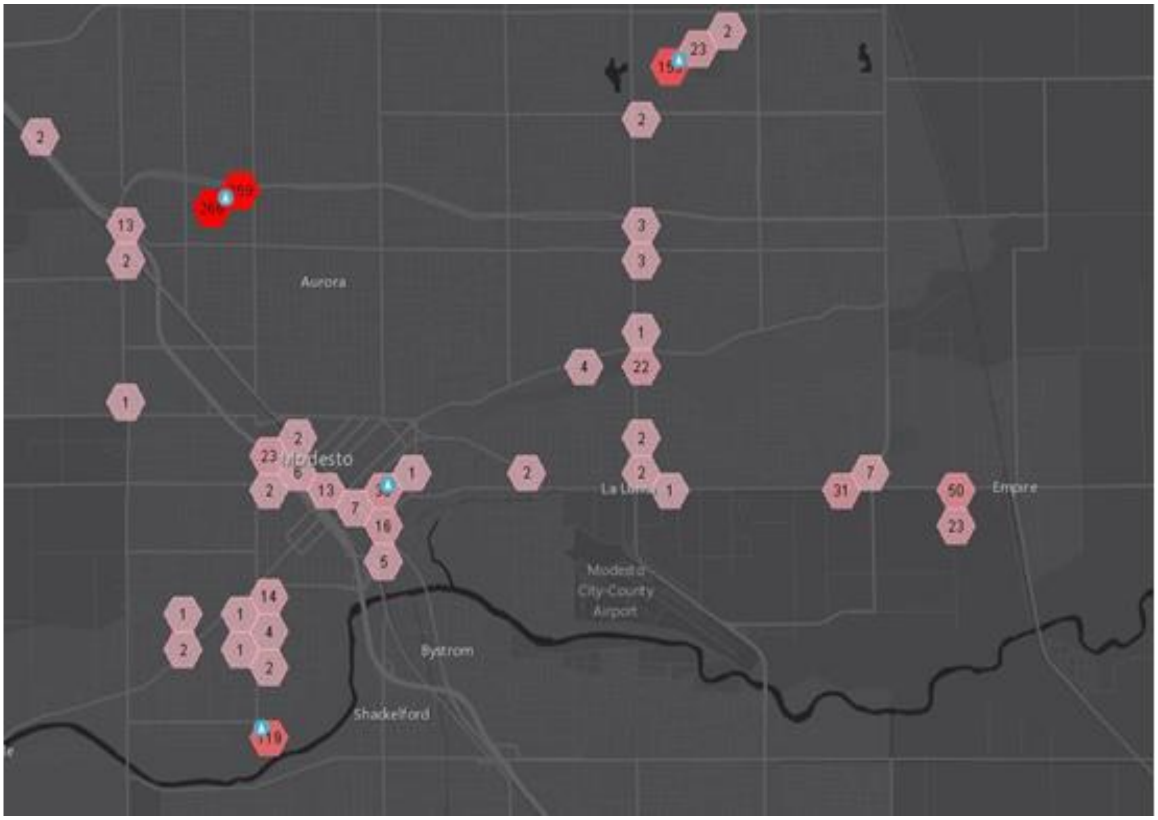
GTI Excavator Testing

Project Number		**Excavator Operator**	Bill Mulligan	**Date**	30-Mar-17
PI		**Excavator Make**	CAT	**Time**	
PM		**Excavator Model**	303.5SE (mini excavator)	**Test #**	
Data Recorder	**David Feliciano**	**Notes**	GoPro time is off by 66 min	**Weather conditions**	
Devices		**Test Location**		**Temperature**	

Test #	Activity	Sub-activity	Description and Timing	Outrigging Deployed	Time Start	Time End	Notes
1	**Idle**						
1A		low/regular	4 minutes at LOW (1) RPMs		920	924	Will have to look at catalog to relate throttle level of 1 to RPMs
1B		high	4 minutes at HIGH (10) RPMs		930	935	Will have to look at catalog to relate throttle level of 10 to RPMs
2	**Driving**						
2A		On gravel drive	7 minutes total, drive 3.5 minutes pause 20 seconds and repeat. Drive at ______ mph.		941	949	Was in "turtle" mode until 945 then "rabit" mode for duration. Had boon in proper position to keep weight balanced.
2B		Varying speeds	4 minutes total, drive 1 minutes pause 20 seconds and repeat three times. Start at lowest speed and accelerate to highest safe speed.		952	956	Did not drive and pause every 20 seconds as the procedure says.
3	**Stopping**	drive 20 ft, stop, reverse, stop	4 minutes total		959	1002	For the first two back-and-forth drives the cab swung 180
4	**Stationary**						
4A		Rotating cabin 360 degrees (excavator only)	Three rotations total, pause 20 seconds before repeating action.		1004	1006	Did 5 rotations total. 2 then pause, 1 then pause, 1 then pause, 2 then pause.
4B		Slow in 45 deg increments (excavator only)	3 minutes total, pause 20 seconds before repeating action.		1007	1009	Turned cab in 90 degree rotations instead of 45
4C		While digging	4 minutes total. Pick up earth and drop, do not move dirt to another location.		1013	1017	During digging throtle would be set to maximum. The cab only moves slightly.
4D		Extend arm and back	3 minutes total, pause 30 seconds before repeating action.		1021	1024	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.
5	**Extend arm while excavating**						
5A		Dig, pickup, move, drop	5 minutes total.		1028	1034	
6	**Moving and dragging equipment/dirt**		3 minutes total				SKIP
7	**Backfill**	(Backhoe only)	10 minutes total		1044	1045	The operator executes lots of fast movements. Uses small blade on excavator to complete this.
8	**Deploy Outrigging**	(Backhoe only)	2 minutes total, pause 10 seconds before repeating action. Repeat deploying and retracting outrigging.				
9	**Obsticle Course**		35-40 minutes total. Dig a __5_x_5__ 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).		1114	1154	Digging started @ 116 ended at 1128 @1130 traveled @1232 trenching until 1145 @1147 backfill

Source: Gas Technology Institute

Figure 37: Digging Activities for a Specified Data Range



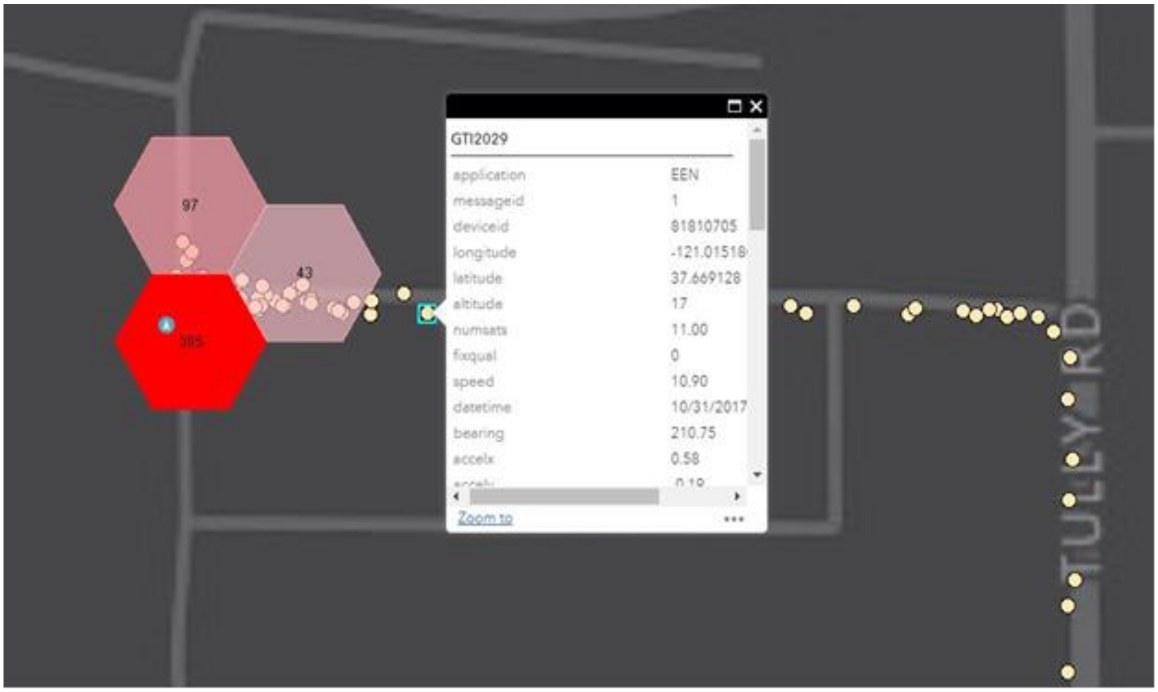
Source: Gas Technology Institute

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

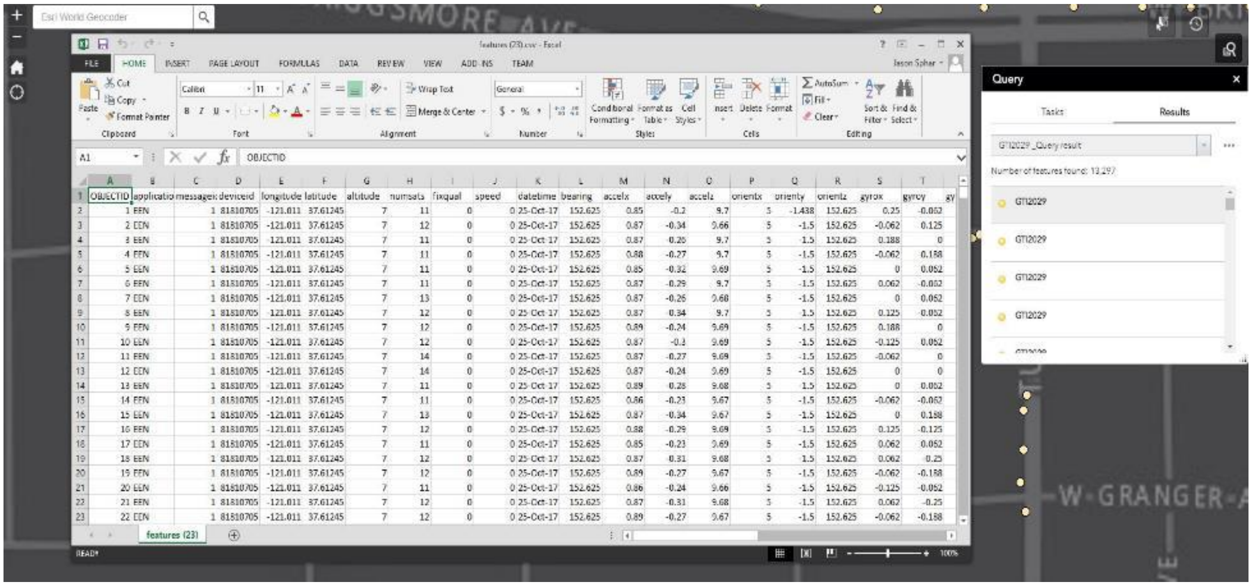


Source: Gas Technology Institute

Figure 39: Query Tool for Device and Date Search

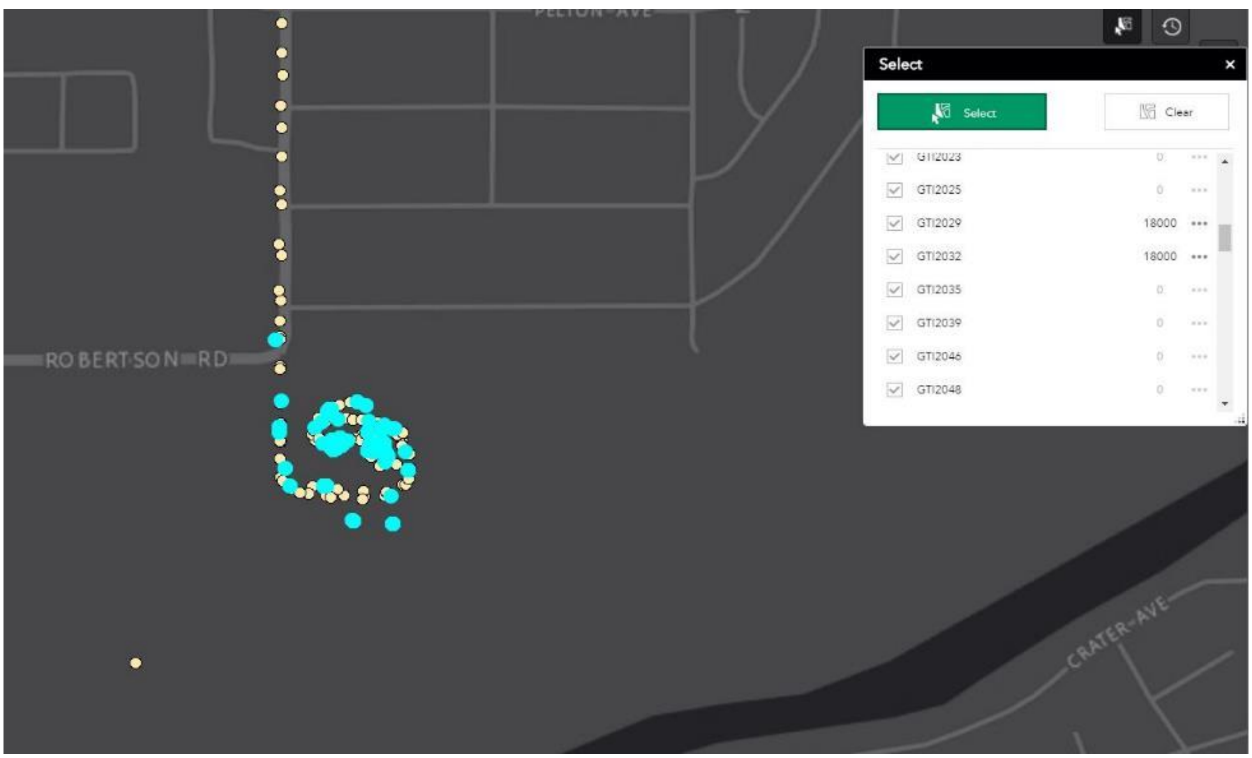
Source: Gas Technology Institute

Figure 40: Results of the Query Tool



Source: Gas Technology Institute

Figure 41: Results of the Select Tool



Source: Gas Technology Institute

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

Source: Gas Technology Institute

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.

Figure 43: EEN Device Registration Form

GTI2518

CreationDate	11/29/2017
Creator	
EditDate	12/1/2017
Editor	
Device Name:	GTI2518
Installer's Name:	
Installer's Company:	SoCalGas
Operator's Company:	SoCalGas-Industry Base
Point of Contact:	
Contact's Phone Number:	
Contact's Email:	
Machine Type:	Backhoe
Other - Machine Type:	
Description of Equipment Used:	580M
Open or Closed Cab:	Open
Operation Type:	Other
Other - Operation Type:	Company owned backhoe
Device Location inside of Cab:	Top left post of dig bucket side
Additional Notes:	At Industry Base

Source: Gas Technology Institute

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.

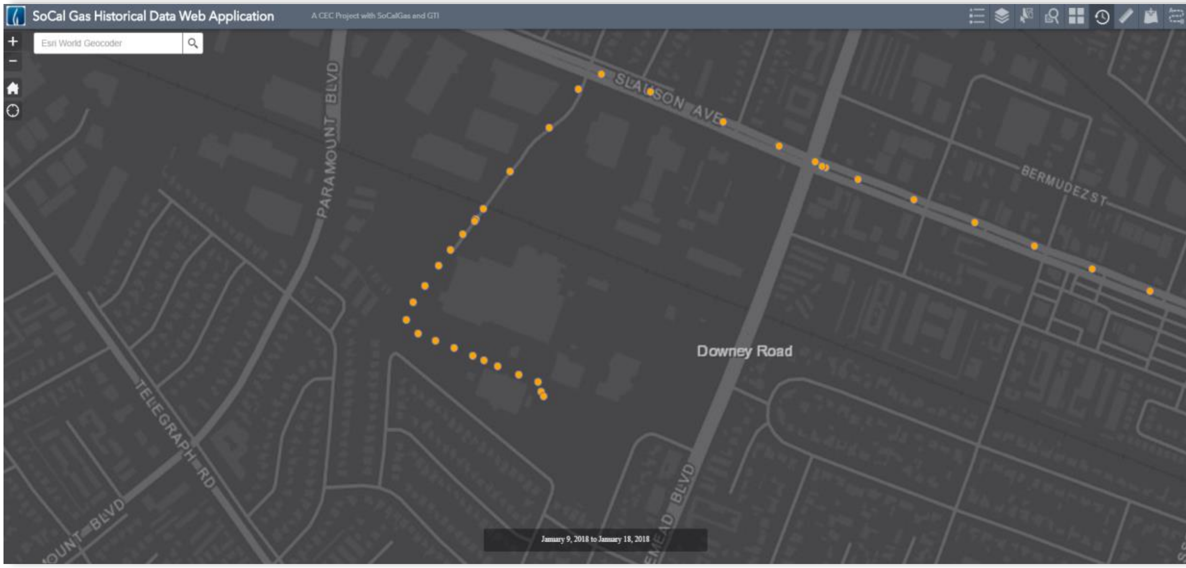
****

This email was generated by the Esri GeoEvent Processor

Source: Gas Technology Institute

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

OPERATOR_NAME	EXCAV_ ONECALL	EXCAV_ LOCATING	EXCAV_ EXCAV	EXCAV_ OTHER	EXCAV_ DAMAGES	EXCAV_ TICKETS
CITY OF SUSANVILLE	3	0	0	0	3	578
ISLAND ENERGY	0	0	0	0	0	132
ALPINE NATURAL GAS	4	0	0	0	4	261
COALINGA, CITY OF	0	0	0	0	0	0
WEST COAST GAS CO INC	0	0	0	0	0	293
LONG BEACH GAS DEPT, CITY OF	16	4	20	8	48	10,765
CITY OF VERNON	0	0	0	0	0	1,406
SAN DIEGO GAS & ELECTRIC CO	161	24	133	87	405	123,726
SOUTHERN CALIFORNIA GAS CO	1,589	254	726	731	3,300	627,116
PACIFIC GAS & ELECTRIC CO	860	204	734	8	1,806	858,972
PALO ALTO, CITY OF	13	8	11	3	35	5,131
SOUTHERN CALIFORNIA EDISON C(	0	0	0	6	6	159
TOTAL	2,646	494	1,624	843	5,607	1,628,539

Source: https://www.phmsa.dot.gov/data-and-statistics/pipeline/distribution-transmission-gathering-lng-and-liquid-annual-data

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

Consequence	Average Per Year
Number of Fatalities	0.29
Number of Injuries	1.86
Gas Ignition, in 1000 ft^3	66,760 MCF
Public Property Damage	$ 285,920
Operator's Property Damage	$ 1,318,254
Emergency costs	$ 299,895
Cost of Gas Released	$ 237,000
Total Annual Cost	$ 2,178,700

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

YEAR	GAS RELEASED (MCF)	FATALITY	INJUREY	SHUTDOWN	IGNITION	EXPLOTION	PUBLIC EVACUATED	COST OPERATION ($)	COST GAS RELEASED ($)	COST PROPERT ($)	COST EMERGENCY ($)	TOTAL ($)
2010	8,500	0	0	NO	NO	NO		0	0	82,000	0	82,000
2010	12,000	0	0	YES	NO	NO	0	0	42,892	47,000	620	90,512
2010	63,410	0	0	YES	NO	NO	0	0	285,000	150,000	10,000	445,000
2011	1,500	0	0	YES	NO	NO	0	0	0	55,000	5,000	60,000
2011	2,000	0	0	YES	NO	NO	0	0	10,000	60,000	0	70,000
2011	3,270	0	0	YES	NO	NO	0	0	13,000	200,000	1,000	221,500
2012	4,700	0	0	YES	NO	NO		15,000	16,000	465,000	50,000	546,000
2012	7,010	0	0		NO	NO		450	10,450	350,000	0	363,900
2012	51,000	0	0		NO	NO		0	20,010	85,000	0	105,010
2012	3,200	0	0	NO	NO	NO	0	0	10,800	0	25,000	35,800
2012	5	0	0	YES	NO	NO	0	0	0	60,000	0	63,200
2013	1,166	0	0	YES	NO	NO		0	3,300	200,000	200,000	403,300
2013	13,798	0	0	NO	NO	NO		0	40,000	100,000	10,000	150,000
2013	11,300	0	0	YES	NO	NO	0	0	68,000	250,000	1,000	319,000
2014	92,000	0	0	YES	NO	NO		0	414,000	520,000	0	979,000
2014	1,258	0	0	NO	NO	NO		0	4,890	60,000	0	65,427
2014	36,589	0	0	YES	NO	NO	0	0	147,512	63,821	31,000	242,897
2014	27,750	0	0	YES	NO	NO	0	0	153,112	103,375	168,960	425,447
2015	67,000	1	2	YES	YES	YES	3	1,000,000	176,000	642,000	717,000	2,535,000
2015	2,655	0	0	YES	NO	NO	0	0	0	300,000	0	300,000
2015	7,200	1	11	YES	YES	YES	0	80,000	21,100	1,500,000	350,000	1,951,700
2015	1	0	0	YES	NO	NO	0	0	2	85,000	0	87,150
2015	3,784	0	0	YES	NO	NO	6	0	16,225	450,000	0	467,100
2016	232	0	0	YES	NO	NO	0	0	1,000	450,000	0	451,000
2016	12,398	0	0	YES	NO	NO	0	0	33,000	188,587	0	221,587
	433,726	2	13				9	1,095,450	1,486,293	6,466,783	1,569,580	10,681,530

Source: Data compiled from https://www.phmsa.dot.gov/data-and-statistics/pipeline/pipeline-incident-flagged-files

Table 11: Root Causes of Significant Incidents in Gas Transmission System 2010 – 2016

YEAR	CAUSE_DETAILS	NOTIFY CGA_DIRT	EXCAVATOR TYPE	EXCAVATOR EQUIPMENT	WORK_PERFORMED	ONE_CALL NOTIFIED
2010	BY THIRD PARTY	NO	CONTRACTOR	FARM EQUIPMENT	AGRICULTURE	YES
2010	BY THIRD PARTY	YES	FARMER	FARM EQUIPMENT	AGRICULTURE	NO
2010	BY THIRD PARTY	NO	FARMER	FARM EQUIPMENT	AGRICULTURE	NO
2011	BY THIRD PARTY	NO	FARMER	FARM EQUIPMENT	AGRICULTURE	NO
2011	BY THIRD PARTY	YES	CONTRACTOR	BACKHOE/TRACKHOE	GRADING	NO
2011	BY THIRD PARTY	NO	FARMER	FARM EQUIPMENT	AGRICULTURE	NO
2012	PREVIOUS EXEC DAMAGE	NO	UTILITY	AUGER	POLE	NO
2012	BY THIRD PARTY	NO	UNKNOWN/OTHER	GRADER/SCRAPER	GRADING	NO
2012	BY THIRD PARTY	NO	FARMER	FARM EQUIPMENT	AGRICULTURE	NO
2012	BY SECOND PARTY	NO	CONTRACTOR	BACKHOE/TRACKHOE	NATURAL GAS	YES
2012	BY FIRST PARTY	NO	UTILITY	BACKHOE/TRACKHOE	NATURAL GAS	YES
2013	BY THIRD PARTY	YES	FARMER	FARM EQUIPMENT	AGRICULTURE	NO
2013	BY THIRD PARTY	YES	CONTRACTOR	FARM EQUIPMENT	AGRICULTURE	NO
2013	BY THIRD PARTY	NO	FARMER	FARM EQUIPMENT	AGRICULTURE	NO
2014	BY THIRD PARTY	YES	FARMER	FARM EQUIPMENT	AGRICULTURE	YES
2014	BY OPERATOR (FIRST PARTY)	YES	UTILITY	BACKHOE/TRACKHOE	NATURAL GAS	YES
2014	BY THIRD PARTY	NO	FARMER	FARM EQUIPMENT	AGRICULTURE	YES
2014	BY THIRD PARTY	NO	CONTRACTOR	GRADER/SCRAPER	GRADING	YES
2015	BY THIRD PARTY	YES	FARMER	FARM EQUIPMENT	AGRICULTURE	NO
2015	BY THIRD PARTY	YES	CONTRACTOR	FARM EQUIPMENT	AGRICULTURE	YES
2015	BY THIRD PARTY	YES	COUNTY	UNKNOWN/OTHER	ROAD WORK	NO
2015	BY THIRD PARTY	YES	FARMER	GRADER/SCRAPER	AGRICULTURE	NO
2015	BY THIRD PARTY	YES	CONTRACTOR	GRADER/SCRAPER	GRADING	NO
2016	BY THIRD PARTY	YES	FARMER	FARM EQUIPMENT	AGRICULTURE	NO
2016	BY THIRD PARTY	YES	FARMER	FARM EQUIPMENT	AGRICULTURE	YES

Source: Data compiled from https://www.phmsa.dot.gov/data-and-statistics/pipeline/pipeline-incident-flagged-files

Table 12: Consequences of Significant Incidents in Gas Distribution System 2010 – 2016

YEAR	GAS RELEASED (MCF)	FATALITY	INJUREY	SHUTDOWN	IGNITION	EXPLOTION	PUBLIC EVACUATED	COST OPERATION ($)	PROPERTY DAMAGE ($)	COST EMERGENCY ($)	COST GAS RELEASED ($)	TOTAL COST ($)
2010	27	0	0	YES	YES	NO	0	0	10,900	0	100	61,000
2011	11,032	0	0	YES	NO	NO	0	0	28,000	2,000	66,000	96,000
2013	844	0	0	YES	NO	NO	50	0	5,000	1,000	5,065	86,065
2013	2,987	0	0	YES	NO	NO	0	0	580,695	1,000	17,922	599,617
2013		0	0	YES	YES	NO		50,000	2,000	2,000	2,000	56,000
2013	11	0	0	NO	NO	NO	0	0	2,500	1,000	275	3,775
2013		0	0	YES	YES	NO		750,000	3,000	0	200	753,200
2013	820	0	0	YES	NO	NO		5,000	47,500	0	2,500	55,000
2013	1,690	0	0	YES	NO	NO		1,000	292,000	5,000	2,000	300,000
2013		0	0	YES	YES	NO		100,000	1,200	1,000	20	102,220
2014	1,228	0	0	YES	NO	NO		0	105,000	0	4,640	109,640
2014	3,251	0	0	YES	NO	NO		0	86,000	0	13,136	99,136
2014	78	0	0	YES	NO	NO		0	115,000	0	315	115,315
2014	4,021	0	0	YES	NO	NO	20	0	500,000	1,500	24,124	525,624
2014	4	0	0	YES	NO	NO	0	0	70,000	0	21	70,021
2014	68	0	0	YES	NO	NO		0	67,203	0	364	67,567
2015	428	0	0	YES	NO	NO	13	0	50,000	0	1,838	51,838
2015	861	0	0	YES	NO	NO	0	0	251,042	200	5,166	256,408
2015	3,185	0	0	YES	NO	NO	100	0	37,081	0	19,113	56,194
2015	293	0	0	YES	NO	NO	0	0	163,600	0	1,260	164,860
2015	240	0	0	YES	NO	NO	12	0	93,000	0	1,027	94,027
2016	701	0	0	YES	YES	NO	0	0	11,540	200	4,206	90,946
2016	1,500	0	0	YES	NO	NO	1	0	193,073	0	0	193,073
2016	330	0	0	YES	NO	NO	0	0	45,663	514,778	1,419	561,860
TOTAL	33,598						196	906,000	2,760,997	529,678	172,711	4,569,386

Source: Data compiled from https://www.phmsa.dot.gov/data-and-statistics/pipeline/pipeline-incident-flagged-files

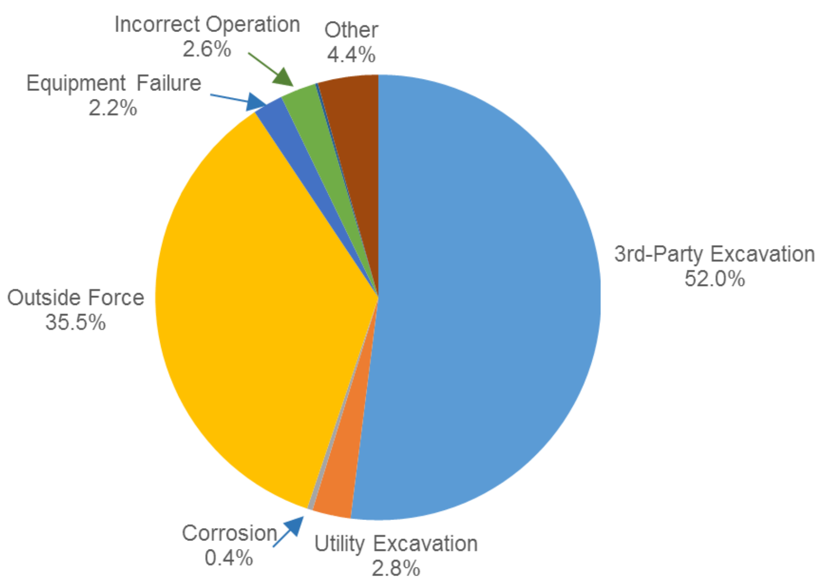
5.2.2 CBUC Records of Excavation Damage to Gas Pipeline System in California

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



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 = 379,000 / [(32,560,000 x 6.62) ÷ 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

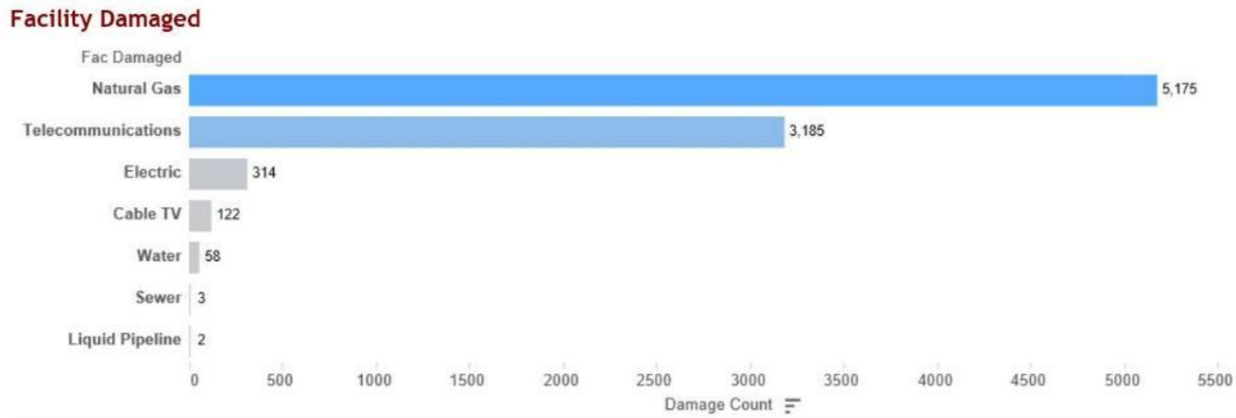
The above data show a damage rate per 1,000 One-Call transmission = 10,074 / [(1,950,000 x 6.62) ÷ 1000] = 0.78

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 x 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 x 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



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

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

Work Performed by Equipment Type

Work Performed	Equipment Type: Backhoe / Trencher	Drilling	Hand Tools	Other Excavation	Grand Total
Agriculture	105 Damages 2.2% of Total	2 Damages 0.0% of Total	83 Damages 1.8% of Total	14 Damages 0.3% of Total	203 Damages 4.3% of Total
Construction/Developm..	448 Damages 9.5% of Total	55 Damages 1.2% of Total	417 Damages 8.9% of Total	127 Damages 2.7% of Total	1,047 Damages 22.3% of Total
Energy	336 Damages 7.1% of Total	59 Damages 1.2% of Total	399 Damages 8.5% of Total	12 Damages 0.3% of Total	805 Damages 17.1% of Total
Fencing	35 Damages 0.7% of Total	39 Damages 0.8% of Total	335 Damages 7.1% of Total	9 Damages 0.2% of Total	418 Damages 8.9% of Total
Landscaping	79 Damages 1.7% of Total	9 Damages 0.2% of Total	263 Damages 5.6% of Total	17 Damages 0.4% of Total	368 Damages 7.8% of Total
Sewer/Water	790 Damages 16.8% of Total	18 Damages 0.4% of Total	532 Damages 11.3% of Total	45 Damages 0.9% of Total	1,384 Damages 29.4% of Total
Street/Roadway	121 Damages 2.6% of Total	13 Damages 0.3% of Total	35 Damages 0.7% of Total	25 Damages 0.5% of Total	193 Damages 4.1% of Total
Telecom	89 Damages 1.9% of Total	58 Damages 1.2% of Total	134 Damages 2.8% of Total	5 Damages 0.1% of Total	285 Damages 6.1% of Total
Grand Total	2,001 Damages 42.6% of Total	252 Damages 5.3% of Total	2,197 Damages 46.7% of Total	252 Damages 5.3% of Total	4,701 Damages 100.0% of Total

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

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

Source: Guide for Communicating Emergency Response Information for Natural Gas and Hazardous Liquids pipelines, HMCRP Report 14, Transportation Research Board, 2014.

4 Guide for Communicating Emergency Response Information for Natural Gas and Hazardous Liquids pipelines, Hazardous Materials Cooperative Research Program, HMCRP Report 14, Transportation Research Board, 2014.

5 U.S. DOT, PHMSA, Significant Pipelines Incidents, 2016, http://primis.phmsa.dot.gov/comm/reports/safety/sigpsi.html#_ngdistrib

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[6]:

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:

[6] High Accuracy Mapping for Excavation Damage Prevention and Emergency Response, Task 4 Situational Awareness User Acceptance Testing Report, California Energy Commission, October, 2017

- 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

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

Source: Guide for Communicating Emergency Response Information for Natural Gas and Hazardous Liquids pipelines, HMCRP Report 14, Transportation Research Board, 2014.

6.2 Technology Commercialization Efforts

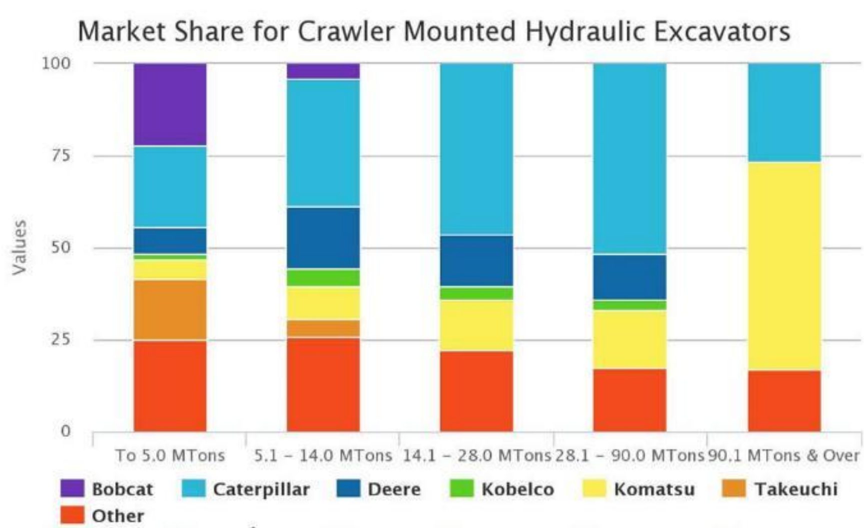
The GPS EEN technology demonstrated how it could reduce the likelihood of excavation damage. The system alerts the utility and the equipment operator when excavation occurs on, or nearby, a pipeline location. Feedback from presenting this pilot study at the Western Regional Gas Conference of the American 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



Source: https://www.technavio.com/report/global-construction-global-hydraulic-excavator-market-2017-2021

[7] Presentation, GPS-Based Dig-In Prevention System, Western Regional Gas Conference 2017, American Gas Association (AGA), Presented by PG&E and GTI, San Diego, CA, August 2017.

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

Company	Type of Operation	Website
Trimble	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	www.trimble.com
TOPCON	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.	www.topcon.com
Leica Geosystems	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.	www.leica-geosystems.com

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[8]. 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 [9]. 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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[8] https://elecsyscorp.com/products/oil-gas-water/

[9] http://www.esri.com/esri-news/arcnews/winter17articles/canadian-utility-goes-real-time-with-mobile-gis

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 15: List of Conferences and Technology Presentations

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

GLOSSARY

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

Term	Definition
AGA	American Gas Association
ArcGIS	Online Cloud-Based Mapping Platform by Esri
CEC	California Energy Commission
CFR	Code of Federal Regulations
CGA	Common Ground Alliance
COP	Common Operational Picture, in Situational Awareness
CPUC	California Public Utilities Commission
DIRT	Damage Information Reporting Tool
DOT	Department of Transportation
EEN	Excavation Encroachment Notification
Esri	Environmental Systems Research Institute
GPS	Global Positioning System
GIS	Geographical Information System
GTI	Gas Technology Institute
IMP	Integrity Management Program
LDC	Local Distribution Company
NTSB	National Transportation Safety Board
M2M	Machine-to-Machine Technology
PG&E	Pacific Gas and Electricity Company
PHMSA	Pipeline and Hazardous Materials Safety Administration
ROW	Right-of-Way
SA	Situational Awareness
SoCal Gas	Southern California Gas company

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U.S. Department of Transportation, Pipeline and Hazardous Materials Safety Administration (PHMSA), Pipeline Performance Measures, https://www.phmsa.dot.gov/data-and-statistics/pipeline/national-pipeline-performance-measures

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

Products:

- 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

- 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:
    - Outcome of product development efforts, such as copyrights and license agreements
    - Units sold or projected to be sold in California and outside of California
    - Total annual sales or projected annual sales (in dollars) of products developed under the Agreement
    - Investment dollars/follow-on private funding as a result of Energy Commission funding
    - 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.

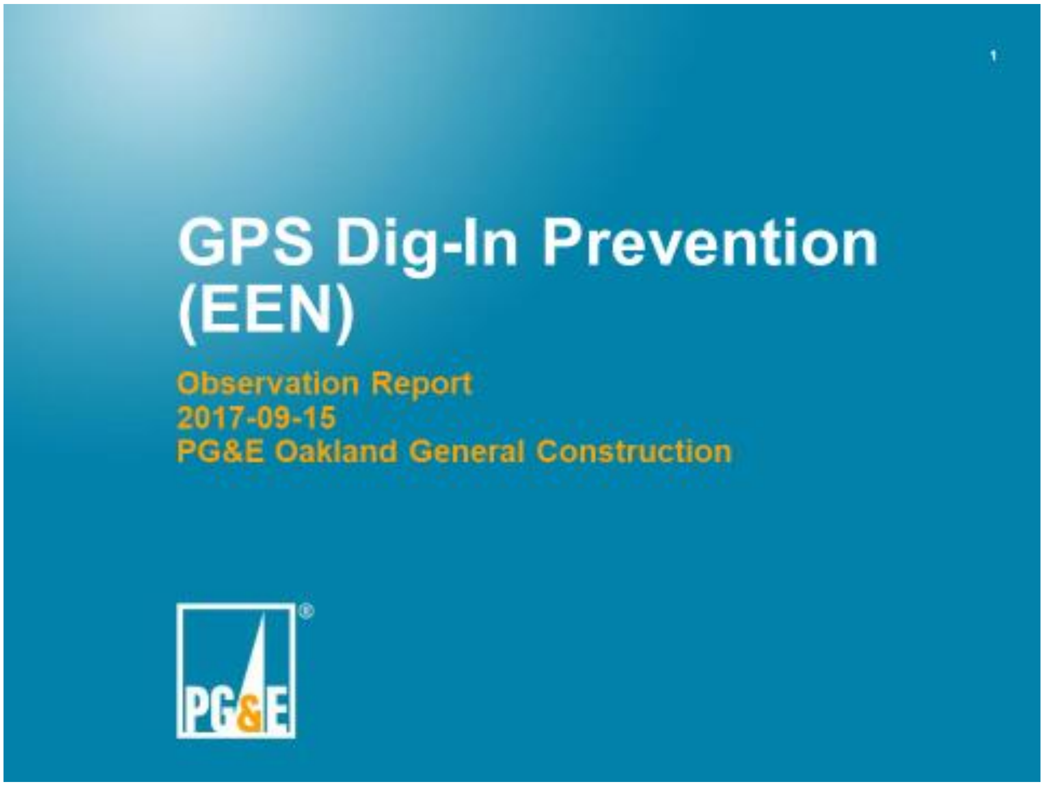
The Recipient shall:

- 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:
  - 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
  - A description of the intended use(s) for and users of the project results
  - Published documents, including date, title, and periodical name
  - 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
  - A discussion of policy development. State if project has been or will be cited in government policy publications, or used to inform regulatory bodies
  - The number of website downloads or public requests for project results
  - 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

<u>Products:</u>

- 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)



Details of Observation

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

Picture of Excavation Machine

GPS Dig-In Prevention Device Observation Report
Prepared by: Rodney Davis, Fisher & Nickel, rdavis@frontierenergy.com

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

GPS Dig-In Prevention Device Observation Report
Prepared by: Rodney Davis, Fisher & Nickel, rdavis@frontierenergy.com

5

Picture showing EEN device installation

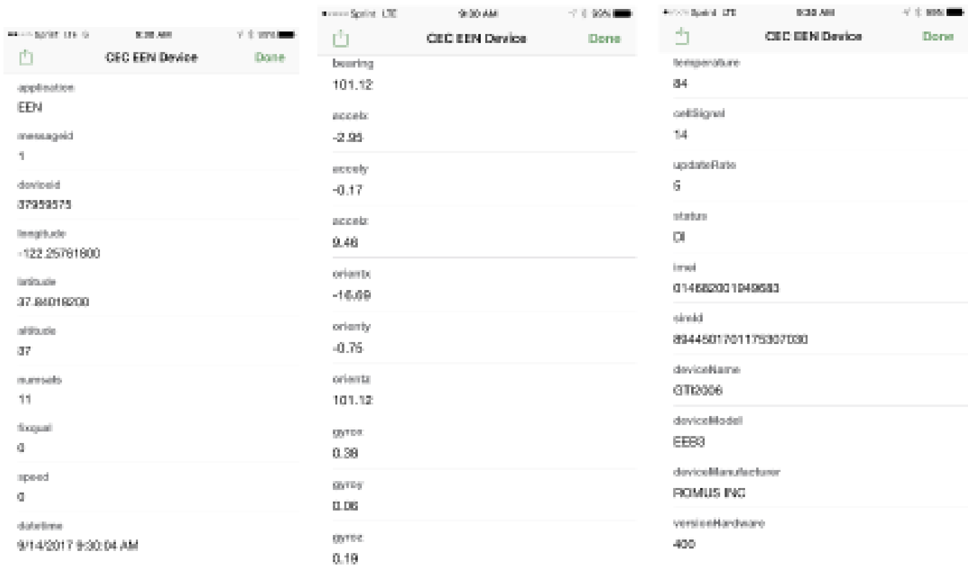
GPS Dig-In Prevention Device Observation Report
Prepared by: Rodney Davis, Fisher & Nickel, rdavis@frontierenergy.com

6

Explorer App Screen Shot of Device on the map

GPS Dig-In Prevention Device Observation Report
Prepared by: Rodney Davis, Fisher & Nickel, rdavis@frontierenergy.com 7

Explorer App Screen Shot of Device Pop-up Window



GPS Dig-In Prevention Device Observation Report
Prepared by: Rodney Davis, Fisher & Nickel, rdavis@frontierenergy.com 8

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

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

Pictures of Job Location

Picture of trench with shoring

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

Pictures of Job Location

Picture of trench with shoring more main uncovered

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

Pictures of Machine Digging

Pictures Showing Additional Observations

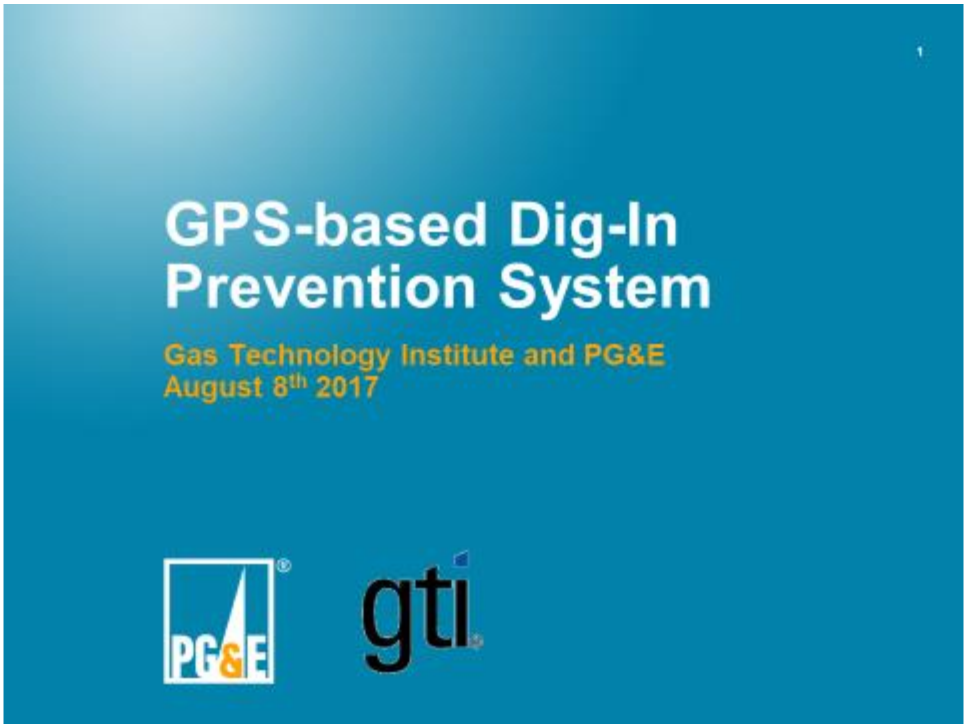
Picture showing bucket used to pull main underneath plates and underneath shoring

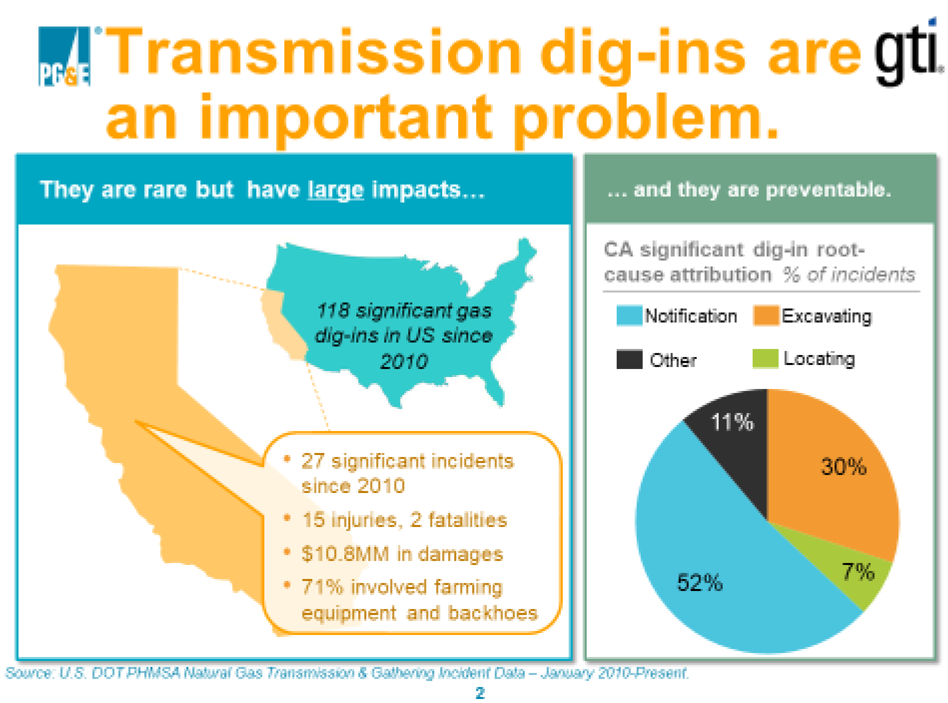
GPS Dig-In Prevention Device Observation Report
Prepared by: Rodney Davis, Fisher & Nickel, rdavis@frontierenergy.com

Pictures Showing Additional Observations

Bucket used to move dirt from truck bed and backfill a portion of the trench

APPENDIX C:
Western Regional Gas Conference (Presentation)





We already do a lot to prevent these incidents.

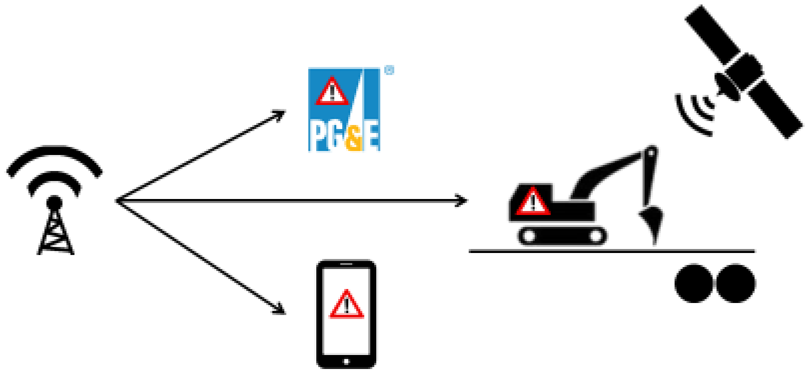
3

Are we doing enough?

4

What if we could use GPS to raise awareness?

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



6

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

https://gti.maps.arcgis.com/apps/opsdashboard/index.html#/827b0043262c43e2875191 3e8c58722e

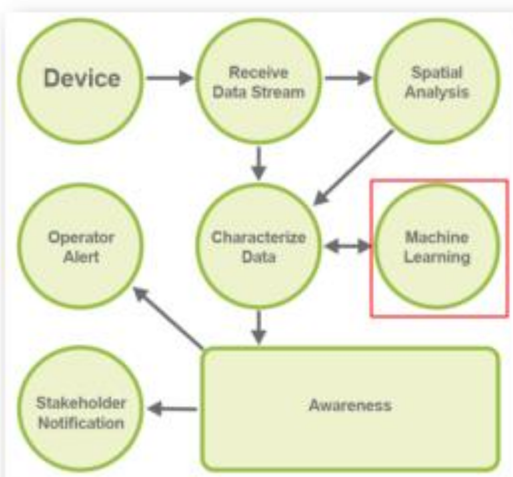
7

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

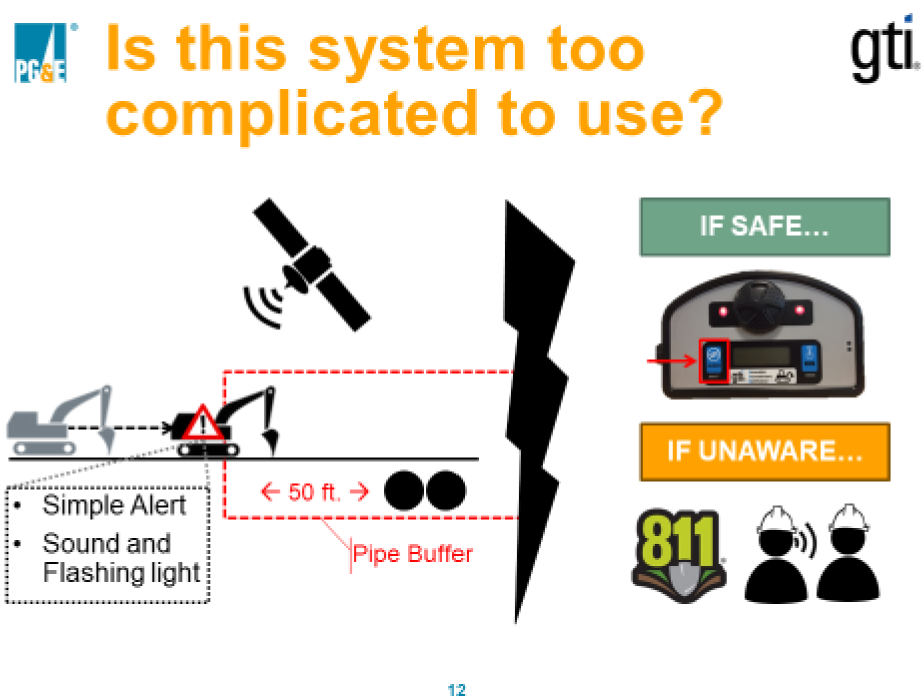
9

Key Features of the System



10


Key Features of the Awareness Dashboard
gti
Devices Online
Alerts Triggered
Main Map
Devices Issues
Devices Digging
Historical Data Counts
Devices Registered with the Project
11


Is this system too complicated to use?
gti
IF SAFE…
IF UNAWARE…
811
• Simple Alert
• Sound and Flashing light
← 50 ft. →
Pipe Buffer
12

Is this going to create too many alerts?

13

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.

17

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

18

Technology without commercialization…

Innovation

=

Invention + Commercialization

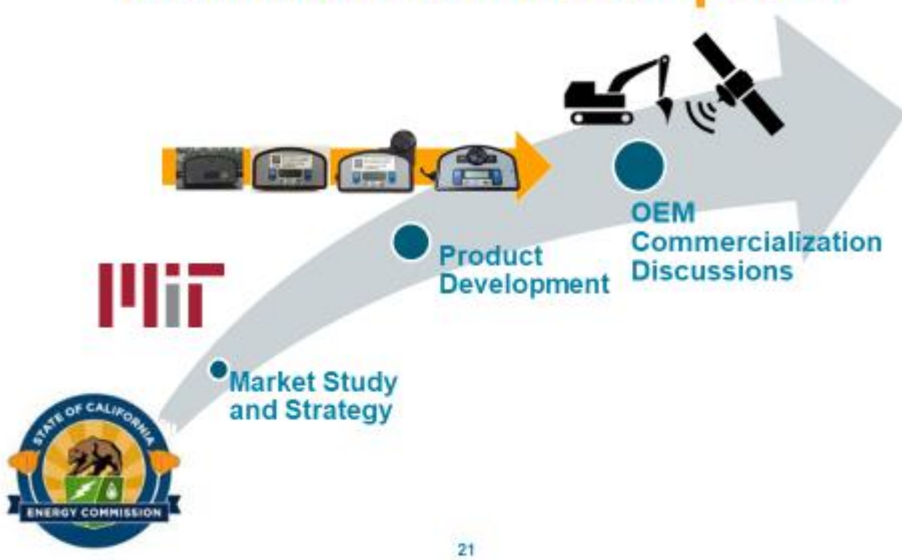
Vs.

19

Commercial Vision

20

Technology is on a commercialization path.



21

How do you get to zero?

22

What is the hold up?

23

Utility Advocates

24

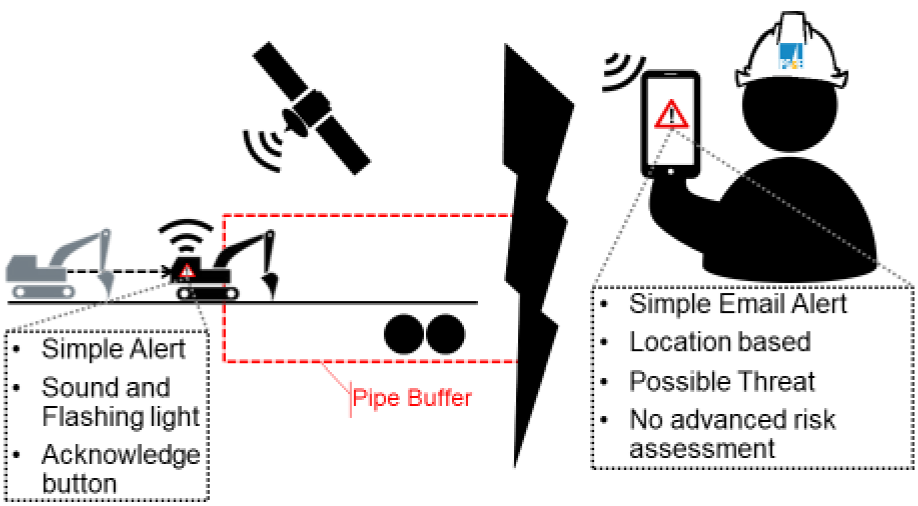
Industry Advocates

25

Regulatory Advocates

26

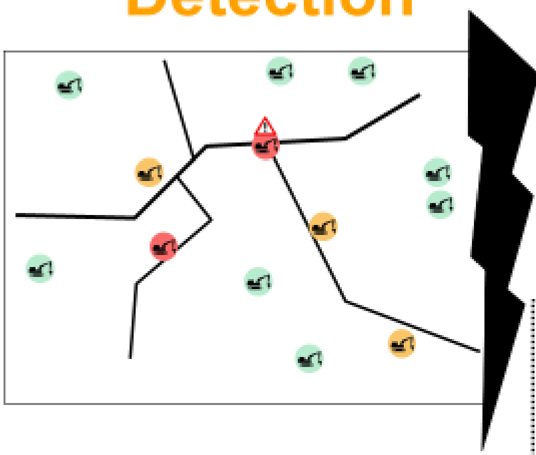
Current Solution: Early Warning System

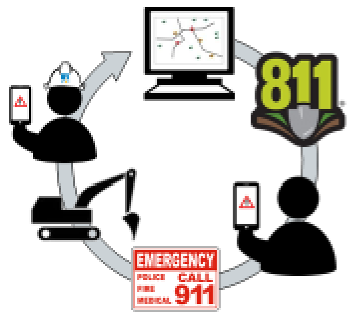


31

Future Solution: Advanced Threat Detection

gti



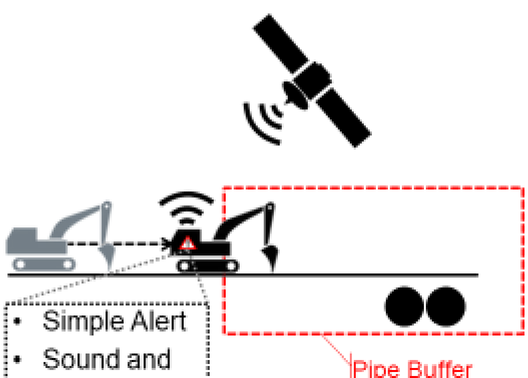


- Different Risk-Based Alerts
- Dashboard or Mobile
- Includes Detailed Information: Who, Activity, USA Ticket, HCA, Standby, etc.

32

Use Case: Equipment Operator

gti



- Simple Alert
- Sound and Flashing light
- Acknowledge button

Benefits
• Enhanced safety
• Avoided incidents
• Simple to use and understand.

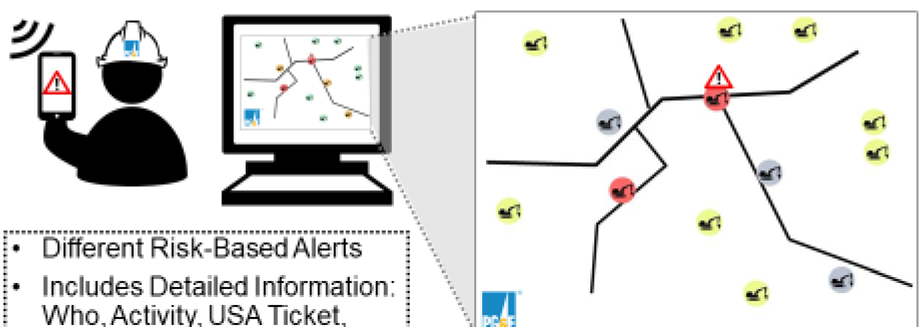
33

Use Case: Equipment Owner/Manager/Foreman

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

34

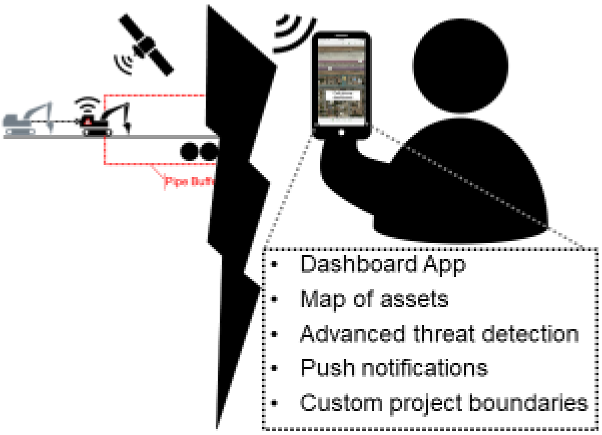
Use Case: Utility (Future State)



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

35

Use Case: Equipment Owner/Manager/Foreman (Future State)



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

36

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 its clear that keeping this technology low cost is key to adoption.

37

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