UNIVERSITY of HOUSTON

CULLEN COLLEGE of ENGINEERING
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Final Report

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GLOSSARY OF TERMS

CGA – Common Ground Alliance

GEENS – GPS Excavation Encroachment Notification System

GIS - Geographic Information System

GPS – Global Positioning System

GTI – Gas Technology Institute

PHMSA - Pipeline and Hazardous Materials Safety Administration

TAC – Technical Advisory Committee

UH – University of Houston

EXECUTIVE SUMMARY

The University of Houston, in partnership with the Gas Technology Institute, and with support from the Commercial Remote Sensing & Spatial Technologies Program at the U.S. Department of Transportation undertook a pilot project to mitigate pipeline damage due to excavation by developing a real-time excavator encroachment notification system. The system used Global Positioning System (GPS) technology, smart phone motion sensor devices, two-way messaging, and Internet Geographic Information System (GIS) services to monitor pipelines, in real-time, for encroachment from excavation activities. In cooperation with several pipeline industry commercial partners, the team, led by UH undertook a pilot study to assess the effectiveness of the prototype low-cost encroachment notification system to monitor encroachment in real-time, and actively pursued commercialization opportunities for the resultant hardware and software products. The primary market for GEENS is the utility market and a secondary market is utilities that operate and maintain electric, telecommunications, and water centric infrastructure. Commercialization and outreach activities included 13 demonstrations and presentations at industry events such as the American Gas Association Annual Operations Conference; exhibitions at industry conferences such as national and state trade association shows; direct outreach to utilities as well as excavator manufacturers and insurance agencies; and advertisements in trade journals and informational webinars to the targeted industries. Partnerships with excavation contractors and with consulting and service organizations in the industry were also developed. Based on the results from pilot testing and from benefit-cost analyses, it is concluded that GEENS represents a *smarter and more efficient* method for reducing pipeline damage incidents and that the benefits from GEENS far outweigh the cost of technology implementation.

I – PROJECT SUMMARY

Background And Need

The overarching motivation for this project is the DOT emphasis on technology applications that deliver "*smarter and more efficient methods, processes and services for transportation infrastructure development and construction*." Encroachment and excavation damage has been and continues to be widely recognized as the single greatest threat to pipeline integrity with similar impacts on public safety. Excavation damage has accounted for 19% percent of the transmission and nearly 40% of distribution pipeline incidents since 1992 according to the Pipeline and Hazardous Materials Safety Administration (PHMSA) data (see Figure 1 below). Excavation damage causes customer outages, requires repairs, and is a significant threat to public and worker safety. The ability to monitor the ROW (right-of-way) for excavation activity and deploy mitigation resources in real-time to prevent damage has immediate value to operators, regulators and the public.

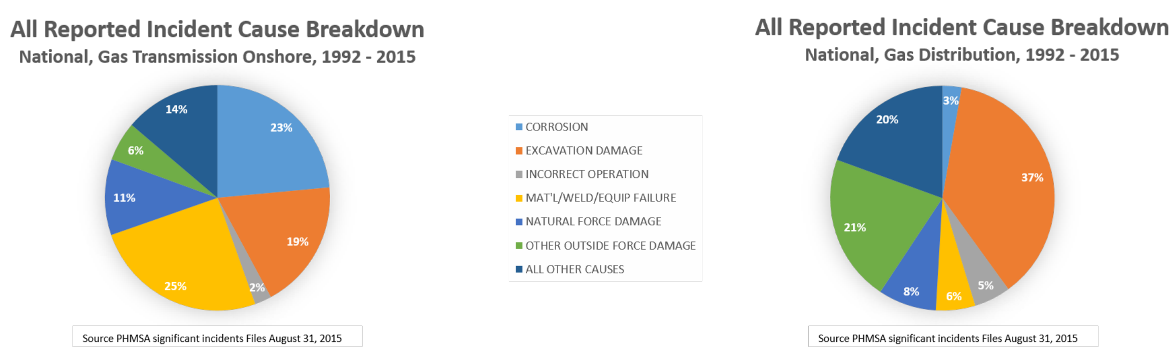

Figure 1: Natural Gas Incident Cause Breakdown for Onshore Transmission (left) and for Distribution (right): 1992-2015.

Current encroachment warning suffers from the fundamental limitation in that it relies on the excavator operator or company to have the pipeline located before digging by utilizing the one-call center, and having the pipeline location manually marked – normally by locating it with electromagnetic sensors. The Common Ground Alliance (CGA) publishes reports on the national rates and causes of excavation damage. Year after year, the two leading causes of excavation damage are excavators that do not utilize the utility notification one-call center and excavators that dig carelessly near utility lines (Figure 2). To overcome these obstacles, we require the knowledge of when the excavator is in proximity to a pipeline. This requires either the real-time location sensing of the pipeline from the excavator, or a real-time tracking of excavator movement with respect to known pipeline locations (Lothon and Akel, 1996). The first option is impractical because current underground line locating technology normally requires an electric connection to the pipeline to sense. This is not feasible for large-scale adaptation, and therefore the second option has been selected as the most probable methodology for mitigation of this problem.

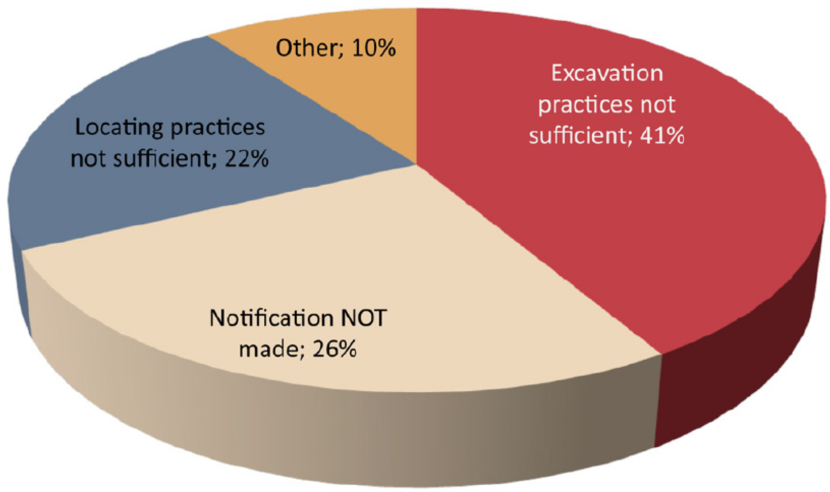

Figure 2: Common Ground Alliance Statistics (1992 to 2015) for causes of excavator damage

To fill this gap in knowledge, the University of Houston (UH) partnered with the Gas Technology Institute (GTI) and Operations Technology Development, a non-profit consortium of 24 natural gas utilities that collaboratively fund research and development efforts within the natural gas industry, to further develop and demonstrate a system that uses Global Positioning System (GPS) technology, two-way messaging, and internet Geographic Information System (GIS) services to monitor pipelines, in real-time, for encroachment from excavation activities with the ultimate goal of preventing pipeline damage. The system developed was named GEENS (GPS Excavation Encroachment Notification System) and leveraged initial technology that GTI had developed in 2005 for Virginia Utility Protection Services (VUPS). The VUPS project was a technical success, but the hardware required was cost prohibitive for wide-scale commercial adoption and therefore one of the primary drivers of this project was to configure a low cost alternative (less than $1000 per installation) that could be widely deployed.

II – PROJECT WORK EFFORT

Section 1. Hardware Development and Instrumentation

The project team performed an exhaustive review of hardware options for excavation activity tracking. The functionality requirements provided by the technical advisory committee and operators were used to make the final selection and considered evaluation of criteria including accuracy, price, two-way messaging functions, and communication method. Final hardware choices were made by the end of the third quarter of the project. There was a slight delay in this selection because the initial technical advisory committee meeting couldn't be scheduled until early in the second quarter of 2014. A description of the selected hardware is given below.

Since the completion of the VUPS project, the ubiquitous nature of smartphones, currently 1.9 billion worldwide and projected to be ~5.6 billion by 2019 (Fitchard, 2013), has driven an explosion of the growth and improvement in the design, development and manufacture of sensors using MEMS (Micro-electromechanical system) technology; leading to a significant improvement in the cost and form factor for a variety of motion sensors (Bogue, 2013; Yang and Hsu, 2010). The majority of consumer smartphones now contain an integrated GNSS chipset and a motion estimation chipset that contains a variety of MEMS sensors including tri-axial accelerometers and gyroscopes, magnetic compasses and pressure and temperature sensors; herein we will refer to these as motion devices. The motion sensors within cell phones have been successfully applied to a variety of applications such as gait tracking (Brajdic and Harle, 2013), health monitoring (Milošević et al., 2011), personal gaming(Lane et al., 2010), indoor and outdoor navigation (Pei et al., 2013; Serra et al., 2010) and remote sensing (Das et al., 2010; Kim et al., 2013).

Given the successful application of consumer grade devices to a variety of motion detection and estimation problems, we quickly settled on the use of consumer cell-phone sensors and next generation low cost GNSS receiver chipsets to both monitor excavator location and excavator operation. Given that consumer devices can give reliable positioning, on the order of a few meters error (Das et al., 2010), our initial focus was to determine whether or not excavator operation can be inferred from the measurements given by the motion devices on the consumer smartphone, i.e. can we determine when an excavator is actively digging in proximity to a pipeline. Determining excavator operation was felt to be critical to reducing the number of false positives that a real-time encroachment system would deliver, as the ideal system should only provide warnings when the excavator is in close proximity to a pipeline AND is actively digging. For this reason, we decided to initially test two different device configurations, (a) a smartphone using the integrated GNSS positioning chip, and (b) the same smartphone device, but with an external higher accuracy (but low cost) GNSS chipset. The primary smartphone (a) was a Samsung Galaxy S4, which contains a Qualcomm WTR1605L GNSS chipset and ST Microelectronics LSM330 6 degree of freedom accelerometer and gyroscope package, and (b) the Nexus4 smartphone, which contains a Qualcomm WTR1605L GPS receiver and Invensense six axis gyro and accelerometer motion tracking devices (MPU-6050). Although the Nexus smartphones contain internal GNSS receivers, we decided to include an external GNSS chipset in our prototype excavator tracking system. As discussed in (Minson et al., 2015), current GNSS chipsets present in smartphones do not allow access to the raw GNSS range observations or raw GNSS solutions, but instead combine a number of sensor measurements together to create a position estimate optimized for consumer navigational needs, such as vehicle navigation and positioning in urban canyons. This approach unfortunately dampens high frequency position changes, which may be of importance for estimating excavator activity. However, recent commercial developments have also provided new smartphone GNSS receivers with carrier phase tracking capabilities suitable for producing phase-smoothed ranges, and have also been augmented (where available) with satellite based differential range corrections (SBAS)(Cina et al., 2014). These new GNSS chipsets are currently only available in a handful of consumer devices, but they are expected to proliferate in devices in the near future (Norman and Warloe, 2015). Therefore, to both provide more accurate positioning for our testing, and also emulate the performance of next-generation consumer devices, we paired our Nexus smartphones with a u-blox NEO-7P precise positioning GNSS module. The NEO-7P provides access to raw code and phase measurements, and also applies real-time SBAS corrections. A picture of the test instrument configuration is given in Figure 3, which shows the Nexus4 connected to both the NEO-7P module on a printed circuit board, and an external battery pack through a split USB cable. The external battery pack is sufficient to run the installation for approximately 24 hours. We have also made

Figure 3: Nexus4 Smartphone with u-blox NEO-7P external GNSS receiver and external battery pack.

accommodations for charging of the battery pack using either the excavator power, or an external solar panel.

A variety of formats of instrumentation packaging were tested throughout the project, with the end goal of ensuring that the installation of the monitoring equipment was seamless and did not impact operations of the excavator. For a majority of the pilot tests, the sensors were rigidly strapped down within the excavator cab inside of a pelican case, with an external GNSS antenna mounted near the cab window to provide skyview. If available the pelican case was attached to excavator power to ensure continuous power. The power connection was not always available, and therefore for some installation the equipment needed to be removed and charged each night. This of course is not an ideal situation. Therefore, the project team also built and tested a ruggedized pelican case that could be magnetically mounted to the top of the excavator. The external mounting allowed the inclusion of a solar panel to provide charging for the sensor package battery and allowed indefinite autonomous operation. A prototype of this external mount system is shown in Figure 7.

Section 2: Software Development and GUI

The software component of GEENS is predominantly a cloud-hosted application hosted by Amazon web services. The system includes a server/web version that analyzes the data from the GPS tracking system to monitor the presence of excavating equipment near the pipeline. The software determines the nature of the excavation activities while providing users with the ability to view excavator locations. Data, including position, velocity and other excavator activity is transmitted from the excavator to the web service using a defined TCP server that is actively monitored by the hosted application. The incoming data stream is then analyzed according to a customizable message-handling model, called the Geo-Event processing model. Based on the results of the analysis, the web software will send a message to the excavator and other pre-designated personnel if encroachment is predicted or detected. The software is built using Esri technology but can be accessed by users without an Esri license. A high level overview of the software architecture is given in Figure 4.

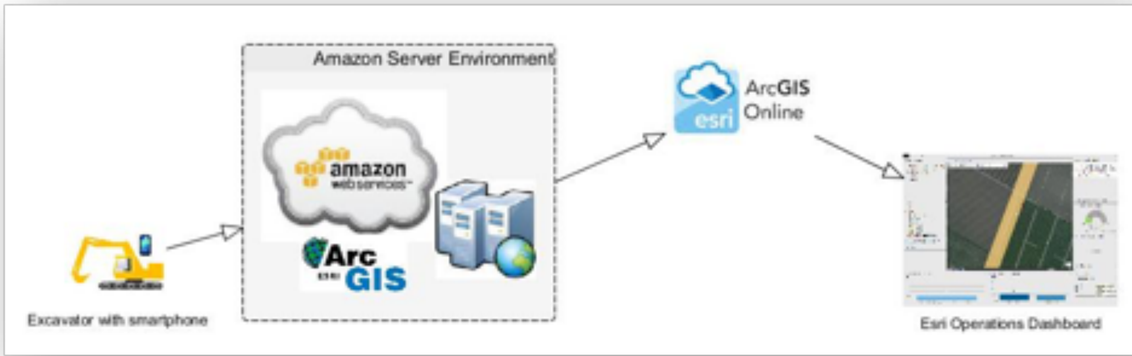

Figure 4: Overview of GEENS Software Architecture

Early on in the project, it was realized that more than excavator location and velocity would be critical for reducing the number of false positives that a real-time encroachment system would deliver, as the ideal system should only provide warnings when the excavator is in close proximity to a pipeline AND is actively digging. Therefore, a significant focus of the software development was to determine whether or not excavator operation could be inferred from the measurements given by the motion devices on the consumer smartphone, i.e. could we determine when an excavator is actively digging in proximity to a pipeline. In order to determine whether an excavator may be of danger to a pipeline, we need to determine both excavator location, and activity. The excavator location can be compared with an existing database of pipeline locations, and if the location is within a user-defined proximity of the pipeline, it can be flagged as a possible hazard to the pipeline. This type of analysis is straightforward, and available in a number of commercial GIS and asset management software packages. However, being located within the pipeline right-of-way or proximity does not necessarily mean that the excavator is of danger to the pipeline – for this to be true, the excavator also needs to be actively digging. This is not possible to detect using only excavator location. In order to characterize activity of the excavator, we defined five possible excavator states: (1) motor off, (2) idle (motor on, not moving), (3) moving, and (4) digging, and (5) unable to determine. We then combined position from the GNSS chipset with the information from the rotation and acceleration sensors within the smartphones (i.e. the gyros and accelerometers in the motion tracking devices) to determine excavator activity. The location enables us to determine whether or not the excavator is moving, and the motion tracking devices allow us to examine the rotation and vibration of the excavator to check motor state (off/on from vibration), and digging activity (rotation). The examination of activity is not instantaneous: we need to examine a finite window of data to accurately determine excavator activity. A longer time window may contain more than one type of motion that increases the difficulty of accurately determining state, however a shorter window will be adversely affected by any data anomalies and will increase the possibility of incorrect determination. We have examined various window lengths, and empirically determined that a 30 second window provides the most consistent results, and therefore is employed in the algorithm. New data is ingested into the algorithm using a sliding window: every five seconds, the oldest 5 seconds of data is deleted and the newest 5 seconds data is added, and the full 30 second window is analyzed to determine state using a machine learning approach. This estimated excavator state is then sent as part of the data message to the TCP server to be used in the Geo-Event processing model.

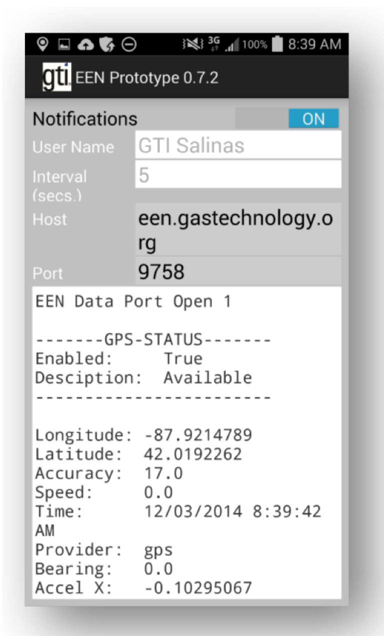

Figure 5: Mobile Smartphone Application for GEENS

In addition to the Geo-Event processing model, specialized software tools were also developed to make the encroachment data available to the users – either excavator operators or pipeline companies. The first software tool is a mobile component that allows the excavator operator to view excavator position relative to the pipeline and/or active One-Call boundaries and graphically defines the excavator's activities that might indicate imminent encroachment. Status messages and encroachment events are also displayed on this mobile application, which is graphically shown in Figure 5. The second tool is a mobile operations dashboard that is run within a web browser and contains a graphical interface and overview map that allows the user to see all monitored excavators, their current activity, along with all right of way boundaries, active One-Call tickets, and current encroachment warnings. It is envisioned that this tool would provide the basis of the pipeline operator or One-Call center monitoring of excavator activity within their service area. The application also has the ability to communicate enroachements and warnings to a variety of enduser groups (owners, operators, monitoring companies) through a variety of formats including SMS messaging and email. An overview of the Operations Dashboard is given in Figure 6. The dashboard allows the user to examine currently operating excavators, pipeline right-of-way boundaries, active one-call center tickets, background base geographical layer information including satellite imagery, along with excavator activity and status in one overview screen. Any alerts and or warnings are also available in real-time through the dashboard interface.

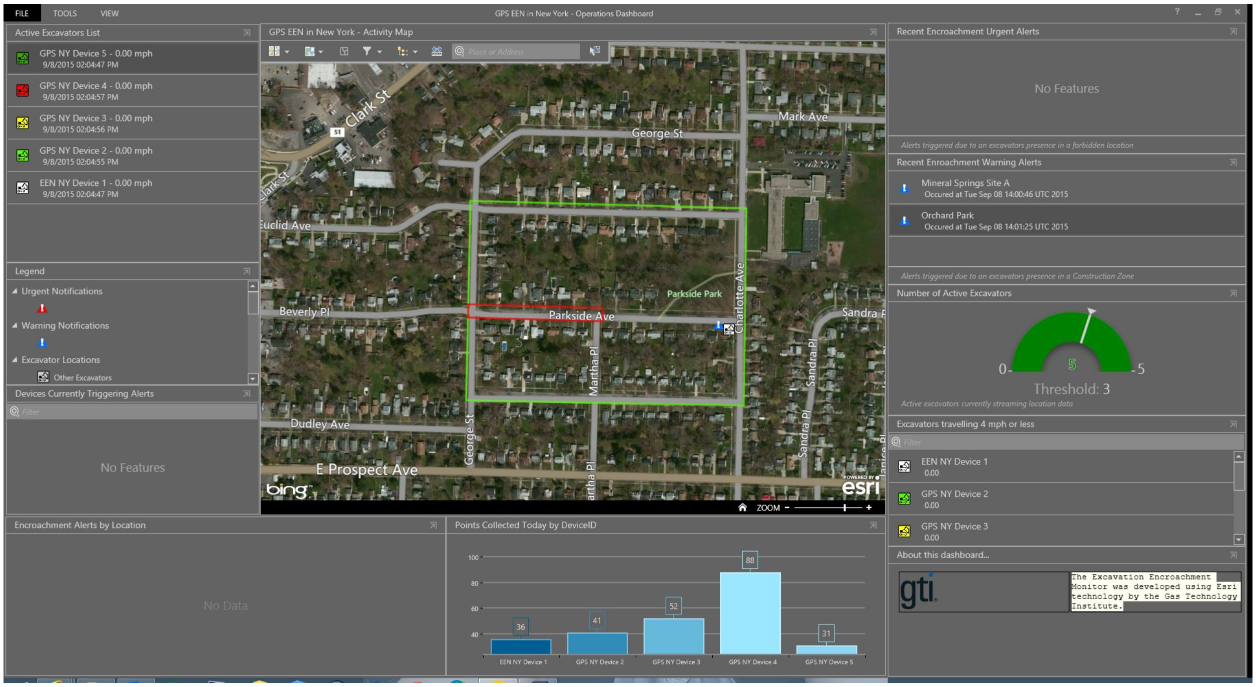

Figure 6: GEENS Operations Dashboard

As previously mentioned, the software has two components. The first is a server / web version that allows users to view excavator activity, monitor encroachment and run reports. The second component is a mobile application that allows users to view excavator activity and encroachment on handheld devices such as smartphones. The software sends an email/text warning to the excavator and pre-designated personnel if excavator encroachment occurs based on pre-defined tolerances. The base functionality of the software had previously been developed by GTI, but the project made a significant upgrade to both the operations dashboard and mobile application to include real-time excavator activity estimation. The GeoEvent processor model was also refined to minimize the number of false positives returned by the system. Although the bulk of the software functionality was in place by the end of the third quarter of the project (Q3 2014), it was refined throughout the duration of the project in response to continuous feedback from both the demonstration tests and the pilot projects.

SECTION 3: FIELD TESTING AND PILOT DEPLOYMENTS

PrePilot Testing:

The software and hardware were demonstrated with a select excavation contractor (CenterPoint Energy) in a pre-pilot project demonstration. The purpose of the demonstration was to solicit feedback to allow changes to be made prior to the pilot project. The initial demonstration took place on November 20, 2014 and was installed on an excavator owned by CenterPoint Energy during an active excavation project (see Figure 7). We collected data for approximately four hours, with the excavator going through a number of maneuvers and active digging. For the entire test period, we also visually recorded the excavator actions as a means of "truthing" our analysis of the raw data provided by each of the sensor systems. A second demonstration test was also undertaken on June 2, 2015, again with CenterPoint energy. This second test was primarily to collect additional truth data with the smartphone motion sensor devices in order to refine the algorithm that was being developed to automatically determine excavator state.

Figure 7: Hardware Components (Silver Briefcase), Installed on Centerpoint Energy Excavator for Testing – 11/20/2014.

Pilot Projects

Two separate pilot projects were undertaken to test the GEENS hardware and software in real-world environments. These pilot projects are summarized briefly below.

GPS EEN – New York

The Gas Technology Institute conducted two pilot projects of the GPS Excavation Encroachment Notification (GPS EEN) technology at National Fuel in Buffalo, NY and also at NYSEG in Binghamton, NY in the Fall of 2015.

The pilot projects consisted of deploying five (5) Samsung Galaxy S5 smartphones running a custom-developed application to collect and send sensor data, location data and other attributes about the smartphone to an Amazon Web Services server running Esri's ArcGIS Server and the GeoEvent Processor Extension.

Each pilot project set out to provide feedback about excavation activity taking place through-out the geographic boundaries of each utility. Each utility was provided with access to the Esri Operations Dashboard software that allowed the utility to track, in real-time, the location of each of the five deployed smartphones and additionally view buffered gas system distribution main. The buffered gas distribution main provided context for the alerting capability of the system to alert utility workers when an excavator was within a certain distance of a gas pipe. The system also provided notification via email or text when an excavator would enter a project area as defined by the gas utility.

Overall, the system performed as expected and provided a much higher level of awareness or visibility regarding the activities of construction contractors within the service territory of the utility. Over the duration of the three-week pilot projects, over 140,000 data points recording excavator movements were collected.

GPS EEN – Texas

The Gas Technology Institute (GTI) worked with the University of Houston through a US Department of Transportation – Research and Innovative Technology Administration (RITA) Project to develop a sensor package consisting of a high-accuracy GNSS receiver, a Qualcomm Snapdragon board, a battery and a solar panel to be mounted on top of an excavator to track and monitor activities of excavators.

GTI provided backend support for collecting and processing data in real-time during the project using Esri's ArcGIS Server and GeoEvent Processor running on Amazon Web Services. The University of Houston developed and tested algorithms based on the movement of the excavators to determine the 'state' of the excavator in real-time as it moved around a construction area.

The pilot project clearly demonstrated that the operations dashboard and smartphone software worked well, and had a minimum of problems in extended tests. The messaging and warning functionality was also shown to be reliable. The major impediment encountered during the testing was ensuring that the system sensors onboard the excavators had sufficient power for continuous operation. This is a critical design component that must be considered when final commercialization of the product is undertaken. At the current time, we feel that the hardware components and software backend are mature enough to deploy with a significant sensor installation with minimal improvements.

III – Outreach and Commercialization

Targeted market

The primary market identified for the GPS EENS is the utility market. Initially, the focus is gas distribution and transmission utilities and municipalities, as well as transmission pipeline operators. There are hundreds of utilities and municipalities that operate over 2.5 million miles of transmission and distribution pipeline in North America. Thousands of excavators operate on utility infrastructure on a daily basis. A secondary market is utilities that operate and maintain electric, telecommunications, and water centric infrastructure.

Addressing the needs of the market, currently not being met with similar technologies

Natural gas utilities incur third party damage to pipelines every day. In 2012, one California based utility operator experienced over 1,000 incidents of damaged pipelines or power lines by excavators. An Illinois based utility on a similar scale also averages over 1,000 incidents annually. This is often the result of a lack of facility locating, a mismarked or inaccurate locate, or the equipment operator is simply unaware that utility infrastructure is present.

Utility operators are also often unaware of where and when excavators are operating near or over their buried infrastructure. There is no current system or technology that provides situational awareness of the excavator location, operating status, asset maps, and related 811 or ROW boundaries in real-time to operating utilities for effective monitoring and decision-making.

Trends affecting market demand

There is an increasing focus on integrity management and safety of natural gas pipelines in North America. As the natural gas infrastructure continues to age and third party excavators continue to damage pipelines, the need for technology providing insight and situational awareness impacting these issues will continue to grow as well. Pipeline incidents, causing human fatalities and damage to the environment, have resulted in increased scrutiny of utility operations by regulatory agencies and by the utility operators themselves. This trend will continue in the foreseeable future to ensure the safety of the public.

Potential market share and a strategy to increase it

GPS EENs is a unique combination of COTS products and software, with custom applications and algorithms, to provide utilities with excavator situational awareness not currently available on the market. Eight of the largest utilities in North America have funded and supported the development of GPS EENS, with five of those piloting or implementing the technology on a non-commercial scale. Through additional deployments, including the California Energy Commission's support of the implementation at Pacific Gas and Electric (PGE), additional organizations will look to adopt this technology as well. GTI expects approximately 50% of the largest natural gas distribution and transmission pipeline operators to implement the GPS EENS over the next five years.

Marketing Strategy

Marketing plan

GTI consistently performs research for approximately 25 of the largest natural gas and electric utility operators in North America. These relationships developed over the past 75 years of GTI's existence will be leveraged to communicate and identify prospective customers. GTI is also very active in many of the largest industry advocacy organizations, such as the American Gas Association.

GTI, as well as the selected commercialization partner, will continue to perform the following marketing and outreach activities to increase market penetration of GPS EENS:

- Demonstrations and presentations at industry events including the American Gas Association Annual Operations Conference, Southern Gas Association, and the Western Energy Institute Operations Conference. The following presentations have been completed under this program:

APGA Security and Integrity (Operations)	Destin, FL	March 2015
Southern Gas Association Operations conference	Nashville, TN	July 20, 2015
Western Region Gas Association	Tempe, AZ	August 26, 2015
National Association of Pipeline Safety Representatives	Tempe, AZ	September 2, 2015
AGA Operations Section Fall Committee Meetings	Amelia Island, FL	September 2015
Northeast Gas Distribution Council		September 30, 2015
National Gas Association Fall Operations Conference	Saratoga, NY	October 9, 2015
Virginia Annual Pipeline Safety Conference	Virginia Beach, VA	October 21, 2015
Operations Technology Development Fall Meeting	Chicago, IL	October, 2015
AGA Operations Conference	Phoenix, AZ	April, 2016
Operations Technology Development Meeting	New Orleans, LA	May, 2016

Atmos Energy Engineering Roundtable	Dallas, TX	May, 2016
AGA Damage Prevention Discussion Group	Denver, CO	June, 2016

- Exhibitions of the technology at industry conferences including national and state trade association shows.
- Direct outreach to utilities as well as excavator manufacturers, and other industries that can impact market penetration such as insurance agencies.
- Advertisements in trade journals including American Gas, Pipeline Gas and Journal, and APGA's The Source (see Figure 8 as an example of marketing material distributed at industry events).
- Perform informational webinars to the targeted industries.
- Develop partnerships with excavation contractors to ensure installation of the sensor package.
- Develop partnerships with consulting and service organizations in the industry, such as Opvantek, who has a complimentary technology solution that assigns risk to specific excavations.

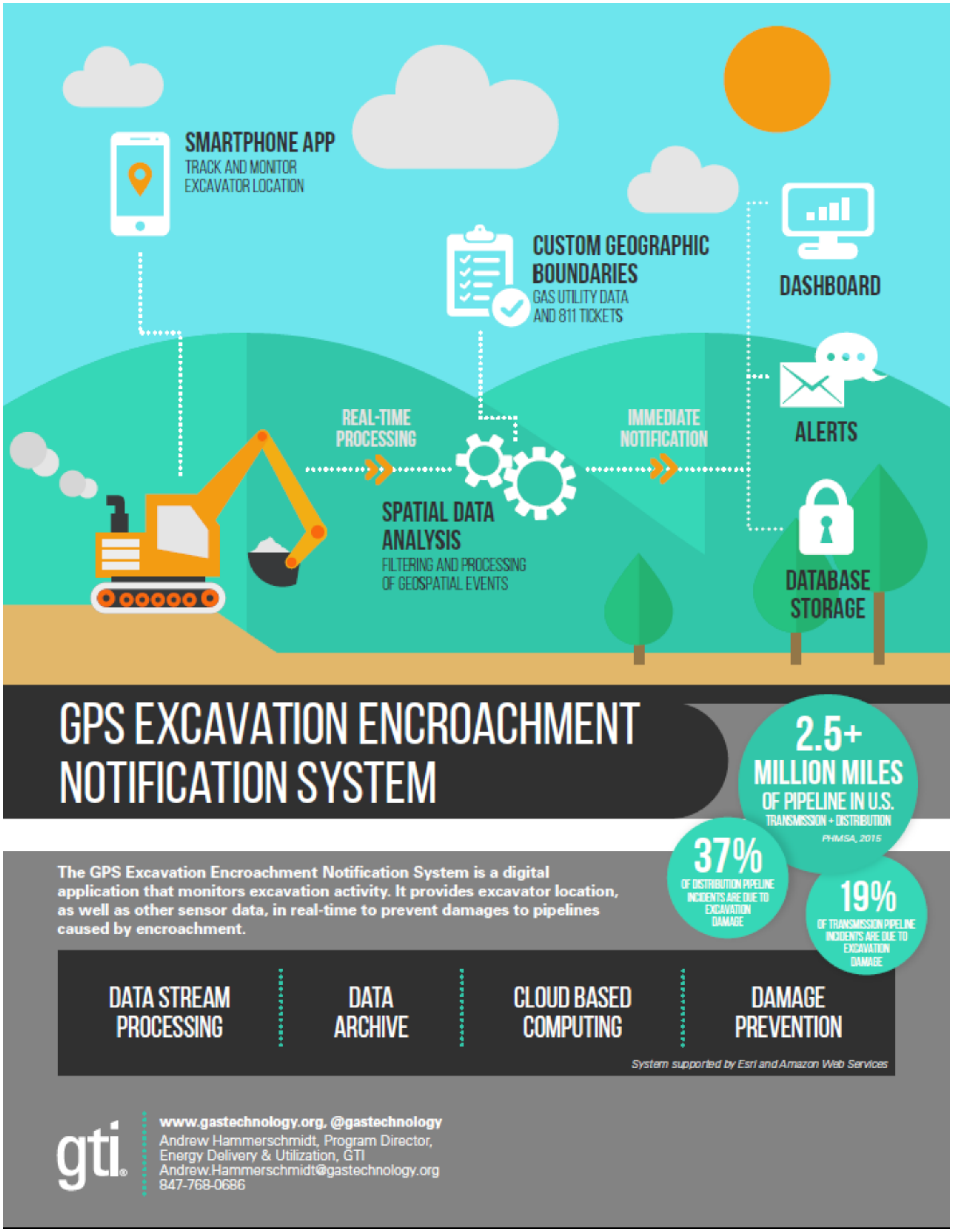

Figure 8: Marketing Material Example

Identification of barriers during deployment and how they will be addressed

Comprehensive Deployment

Technology implementations, whether in the form of software and hardware systems or mechanical tools, often require significant change within an organization. Company-wide adoption can be difficult, particularly when the product is complex or requires significant training requirements. Another barrier is if the technology changes operational or business processes or workflows. Organizations may also be reluctant to replace existing software, or may not have the supporting software for successful implementation. The recommended solution is phased implementations with validation points to ensure the workflows and business processes are robust and fully tested prior to moving to the next stage of implementation. Phased implementations in defined geographic regions can also ensure success is achieved on a small scale before continuing implementation throughout the entire organization. The proposed structure for this implementation follows this recommended solution.

Organizational Support

Technology implementations without executive level support can lose momentum and not receive the funding and attention required to be successful. The solution to overcome this potential barrier is to develop a project charter that clearly links with an executive supported roadmaps and goals and has an executive project "champion" that agrees to support the project through completion.

Commercialization Activities

GTI has searched for and executed non-disclosure agreements with multiple organizations identified as potential commercialization partners. The identification and selection of a commercialization entity has not been completed as of the submission of this report. These activities and negotiations will continue. For purposes of negotiation, the entities will remain confidential.

GTI, via a California Energy Commission Grant, will be performing a 100 to 150-unit implementation of GPS EENs over the next 18 months. Potential commercialization partners will be engaged in this process as well.

Business Model

The final business model will be determined and finalized in coordination with the commercialization entity. Initial evaluation and analysis indicate a subscription service oriented business model would be effective. This would include a service-based partner providing hardware, hardware installation, software and configuration services, and a hosted cloud based server environment for data processing to the primary market users, or utility organizations that require enhanced situational awareness to safely operate their infrastructure.

Successful deployment of hardware to non-utility based customers will require other complimentary measures. Penetration of non-utility excavation equipment, including contractors, construction companies, DOT agencies, etc., will require partnerships and cooperation of organizations including 811 agencies, insurance agencies such as AEGIS (incentives), and construction equipment manufacturers such as Komatsu, John Deere, Case, etc. GTI has reached out to each of these entities to discuss the technology and will continue to develop partnerships with them throughout the commercialization partner selection process.

PRICE

Price as a competitive factor

The primary market driver for implementation of the GPS EENS technology is to enhance public safety, reduce risk of excavation damage to natural gas infrastructure, and increase situational awareness and communication in emergency response situations. While there are operational efficiencies gained in the monitoring and inspection aspect of utility operations, the primary driver is not price related, therefore, GTI does not feel that price is a strong competitive factor in the deployment of GPS GEENS.

A component of the system, the hardware or sensor package installed on each excavation device is more susceptible to price elasticity. Therefore, we are choosing cost effective sensor packages to overcome the price barrier such that non-utility organizations, such as contractors or original equipment manufacturers, will install the sensor package on the equipment.

Estimated purchase price and how it is calculated

The system has multiple components that are each priced separately.

- The sensor package installed on the excavation equipment varies based on the technology used. During the pilot phase of development, SMART phones were installed on the equipment, which carries a cost of approximately $500 per unit. Thus, for implementation at PGE, as well as future deployments, GTI will utilize a custom “black box” approach with inexpensive sensors to reduce the cost significantly. Examples of these are included below in Figure 9 and 10. Our goal is for the price per unit to be under $100. These sensor packages will be available independently of the system to ensure penetration into the excavator market.

- The second component of the system is the configuration and installation process of the system architecture and software application. It is expected to be a one-time expense of approximately $300,000 for a company the size of PGE. On-going support on an annual basis will be approximately 15% of this capital cost.
- The third component is the registration or subscription fee for each excavator equipped with the sensor package. This is a nominal annual fee of approximately $10 per unit.

Figure 9: Black Box Sensor Package Example 1

Figure 10: Black Box Sensor Package Example 2

Cost of technology over time

As indicated above, annual fees for maintaining the server and system architecture, as well as providing technical support, is approximately 15% of the configuration cost per organization. The sensor package is expected to decrease in cost over time as technology continuously improves and drives per unit direct costs down.

How economies of scale affect pricing

Large deployments at companies such as PGE should result in cost savings of approximately 30%. These savings will be achieved through bulk hardware or "black box" purchases and volume discounts on software fees. The direct costs for the sensor package is expected to continue to decrease in the next five years to provide further reductions in system costs.

Continued growth plan

As noted earlier, GTI, via a California Energy Commission Grant, will be performing a 100 to 150-unit implementation of GPS EENs over the next 18 months. With an expectation of continued growth of GPS EENS, GTI will be seeking formal partnerships for the manufacturing and distribution of the sensor package, as well as partnering with organizations such as Esri for continued support of the applications and server environments.

GTI, and the selected commercialization partner, will also continue to seek opportunities to expand GPS EENS through other complimentary service providers. An example of this is Opvantek, Inc, and specifically their Optimain xDR product, which integrates utility pipeline damage records, risk classifications, and geospatially driven 811 locate information to ascertain risk in an excavation zone. GPS EENS would be a natural complement to this product by combining the excavator situational awareness and operation state to the risk profile generated by Optimain xDR. This will provide additional insight and prioritization capability to the utility operator.

Efforts will also be made to expand GPS EENS to other critical infrastructure industries that endure third party excavation damage such as electric, telecommunications, and water utilities.

IV – Business Status

Table 2 compares the budgeted and expended funds on the project to date. Final expenditures will not be available until 30 days after the close of the project, but should reflect that a majority of the budgeted funds have been encumbered.

Table 2: Budget and Expenditures on the Project as Of July 15, 2016.

GPS Excavation Encroachment Exp: 07/14/2016 Budget Category	Budget	As of June 9, 2015 Expended	Balance
Salary & Wage	**$90,834**	**$79,291**	**$11,543**
Fringe Benefit	**$6,315**	**$6,563**	**$(248)**
Capital Outlay	**$0**	**$0**	**$0**
GTI Sub-Contract	**$184,443**	**$183,755**	**$688**
Travel Expense	**$521**	**$521**	**$0-**
M&O	**$5,961**	**$5,171**	**$790**
Indirect cost	**$64,958**	**$64,958**	**$64,958**
Total	$353,032	$340,259	$12,773

V - Findings and Conclusions

As stated previously, encroachment and excavation damage continues to be widely recognized as the single greatest threat to pipeline integrity with similar impacts on public safety. This research found that current technology now allows for the adaptation of the initial technology developed by GSI for VUPS to form GEENS, which is a less costly alternative. The system not only will detect the location of the excavator in proximity to pipelines but will also be able to ascertain the status of it; whether it is digging or not. Because of the proliferation of smart phones and advances in the technology they contain, it is now possible to utilize a common device that most people have to employ the GEENS system together with devices like the NEO-7P GNSS module, that will soon be incorporated in next generation smart phone devices. Similarly, software advances are employed in the GEENS through cloud computing and the use of ESRI software without the need for a costly software license. As the project progressed, feedback from demonstration and pilot testing was incorporated into the software to improve functionality.

The Gas Technology Institute conducted two pilot projects of GEENS at National Fuel in Buffalo, NY and also at NYSEG in Binghamton, NY in the Fall of 2015. More than 140,000 data points were recorded of excavator movements and ground-truthed to actual events. Overall, the system performed as expected and provided a much higher level of awareness or visibility regarding the activities of construction contractors within the service territory of the utility.

Quantitative Estimates of Benefits

The quantification of the benefit of deploying a technology of this type is challenged by the basic premise that the purpose is to use the technology to avoid an incident or to reduce the impact of an incident. In April 2014, the Energy Commission published a report entitled "California Natural Gas Pipeline Assessment: Improving Safety by Enhancing Assessment and Monitoring Technology Implementation". The report included an assessment of 114 past pipeline incident reports from 1969 through 2012 as documented by the National Transportation Safety Board (NTSB). By focusing on incidents on natural gas transmission pipelines that resulted in death, injury and/or property damage; five major root causes emerged.

- 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

- 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
- 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
- Failure to detect, locate, recognize, and respond to a leak or rupture in a timely basis
- Poor response or lack of a coordinated response to an incident.

Pipeline damage caused by excavation is an everyday occurrence in utility operations. A California based utility, in 2012, experienced over 1,000 incidents of damaged pipelines or power lines by excavators. Another Illinois based utility averages over a 1,000 such incidents annually. Recently, a loss of life occurred as agricultural equipment struck a transmission pipeline in California.

The GPS EEN system is designed to significantly increase situational awareness of excavation equipment related to utility infrastructure. This will have an effect of reducing the risk of pipeline incidents caused by third party damage. It is difficult to put a quantitative value on safety.

The avoidance of an incident or the reduction of the impact from an incident has quantifiable benefits in terms of the avoidance of loss of life, reduction or elimination of injury, and/or property damage. To attempt to provide some perspective on the value of avoiding the loss of a single life, reference is made to the value of a statistical life (VSL) as determined by the U.S. Department of Transportation. The first VSL was published in 1993. In 2008, the calculation of the various factors resulted in a VSL of $5.8 million. The VSL was revised to $6.2 million in 2011 followed by an interim adjustment in July of that year, which place the VSL at $9.1 million. The latest revisions to the VSL were released on February 28, 2013 recommending that analysts should only apply low and high alternative values of $5.2 million and $12.9 million.

In addition to loss of life, cost benefits will also be realized through operational efficiencies. For example, a utility response to a pipeline rupture, or even a damaged pipeline without a rupture, results in costs associated with deployment of personnel, equipment, material, as well as excavation and restoration activities. Each incident can be expected to have tens of thousands of dollars associated with it, depending on severity of the event. Severe, DOT PHMSA recordable events can result in hundreds of thousands to millions of dollars in utility expenses.

Utility operators and excavation equipment operators will see immediate benefits upon implementation of the GPS EEN system. It is expected operational efficiencies will be gained as the user of the Operations Dashboard becomes acclimated to the information displayed. Automated communications to pipeline inspectors as well as excavation equipment operators will enhance their situational awareness during normal operating activities.

VI - REFERENCES

Bogue, R., 2013. Recent developments in MEMS sensors: a review of applications, markets and technologies. Sensor Review 33, 300-304.

Brajdic, A., Harle, R., 2013. Walk detection and step counting on unconstrained smartphones, Proceedings of the 2013 ACM international joint conference on Pervasive and ubiquitous computing. ACM, Zurich, Switzerland, pp. 225-234.

Cina, A., Dabove, P., Manzino, A.M., Piras, M., 2014. Augmented positioning with CORSs network services using GNSS mass-market receivers, Position, Location and Navigation Symposium - PLANS 2014, 2014 IEEE/ION, pp. 359-366.

Das, T., Mohan, P., Padmanabhan, V.N., Ramjee, R., Sharma, A., 2010. PRISM: platform for remote sensing using smartphones, Proceedings of the 8th international conference on Mobile systems, applications, and services. ACM, San Francisco, California, USA, pp. 63-76.

Fitchard, K., 2013. Ericsson: Global Smartphone Penetration Will Reach 60% in 2019, http://gigaom.com/2013/11/11/ericsson-global-smartphone-penetration-will-reach-60-in-2019/.

Kim, J., Lee, S., Ahn, H., Seo, D., Seo, D., Lee, J., Choi, C., 2013. Accuracy evaluation of a smartphone-based technology for coastal monitoring. Measurement 46, 233-248.

Lane, N.D., Miluzzo, E., Hong, L., Peebles, D., Choudhury, T., Campbell, A.T., 2010. A survey of mobile phone sensing. Communications Magazine, IEEE 48, 140-150.

Lothon, A., Akel, S., 1996. Techniques for preventing accidental damage to pipelines, International Pipeline Conference: pipelining in a changing competitive environment. American Society of Mechanical Engineers, Calgary, Canada, pp. 643-650.

Milošević, M., Shrove, M.T., Jovanov, E., 2011. Applications of smartphones for ubiquitous health monitoring and wellbeing management. JITA-Journal of Information Technology and Applications (Banja Luka)-APEIRON 1.

Minson, S.E., Brooks, B.A., Glennie, C.L., Murray, J.R., Langbein, J.O., Owen, S.E., Heaton, T.H., Iannucci, R.A., Hauser, D.L., 2015. Crowdsourced earthquake early warning. Science Advances 1.

Norman, C., Warloe, A., 2015. All-Constellation Receiver, GPS World. Questex Media Group, pp. 18-22.

Pei, L., Guinness, R., Chen, R., Liu, J., Kuusniemi, H., Chen, Y., Chen, L., Kaistinen, J., 2013. Human Behavior Cognition Using Smartphone Sensors. Sensors 13, 1402.

Serra, A., Carboni, D., Marotto, V., 2010. Indoor pedestrian navigation system using a modern smartphone, Proceedings of the 12th international conference on Human computer interaction with mobile devices and services. ACM, Lisbon, Portugal, pp. 397-398.

Yang, C.-C., Hsu, Y.-L., 2010. A Review of Accelerometry-Based Wearable Motion Detectors for Physical Activity Monitoring. Sensors 10, 7772.

Appendix A: Meeting Minutes from Technical Advisory Committee/Scoping Study Meeting on April 22nd, 2014

Time: April 22, 2014 – 9:00 am to 12:00 pm

Location: University of Houston Energy Research Park

Present:

Craig Glennie, PI, UH

Hanadi Rifai, Co-PI, UH

Alicia Farag, GTI

Xiaohong Zhang, GTI

TAC Members:

Peter Pedersen, Atmos Energy

Kyle Slaughter, Atmos Energy

Joe Berry, CenterPoint Energy

Rick Daniel, Railroad Commission of Texas

Gweneyette Broussard, Shell Pipeline Company LP

Regrets:

James Dillard, Entergy

Items of Note from Discussion

- TXRRC maintains an active transmission pipeline GIS for TX in geographical coordinates. New transmission pipelines are required (by RRC) to be entered into this database. We should attempt to gain access to this database for the pilot project.
- There are currently no standards for pipeline GIS right of way (ROW) collection, or ROW boundary definition, but these will be a requirement for wide-scale adoption of GEENS.
- Automated notification on excavators in a definite project requirement, but there is still likely a requirement for back office human interaction for decision support.

- Warning system should have different levels, based on priority (e.g. proximity, within valid one-call ticket, no notification etc.)
- If this technology is deployed at the state level, how will out-of-state contractors be included and managed?
- One-call tickets may not be a valid reason for disabling of a warning (relative to the pipeline asset).
- Would be beneficial if the GEENS approach would also be applicable to horizontal drilling rigs. This may become part of the scope for the pilot project.
- The project team should consider focusing on one specific type of excavator/equipment. For example, directional drilling machines are one of the highest risk activities and if this project was able to provide a technology to prevent this risk it would be considered a success and would serve as a platform for expansion. Additionally, the project could focus on contractors performing work for operators and then expand to include other contractors.
- We should note that a majority of operators may not speak English or even have the ability to read. We also need to consider warning indicators, as flashing red lights may not work best for all cultures (e.g. pirate flag registers well with Hispanic population).
- The interface with the equipment operator must be simple and intuitive and should perhaps include an audio warning.
- Warning notifications should also be forwarded to excavator owner, as well as pipeline operator.
- TX 811 may be a viable commercial option to take the place of a service company providing automated warnings, since they already have the GIS and excavator information in house. They also have the notification and ticketing infrastructure in place. Support (and funding) from their members will be required.
- Requirements for hardware tied to insurance costs may be good motivation for excavator operators to acquire technology. We need to explore this with insurance industry.
- A hardware component that is table to measure hydraulic actuator movement may greatly simplify the digging trigger for an excavator.
- We need to start working on pilot project design document to allow TAC plenty of time to provide feedback and coordinate test sites. This document should clearly define the scope of the pilot project and should include information about the type of excavation contractors/equipment should participate.

- TAC committee will be updated quarterly via conference call just prior to submission of quarterly reports.
- Next face-to-face meeting of TAC will be in Q1 of 2015.

Items for Follow-Up:

- Coordinate a visit to the TX 811 center to examine their operation and discuss potential commercial implementation (Alicia/GTI)
- Search for hydraulic actuator sensor components (Craig/UH)
- Email TAC presentation and website address to TAC members (Craig/UH)
- Field visit of UH team to Centerpoint Energy excavation site, coordinate with Joe Berry (Craig/UH)
- Begin generation of pilot project design document (Craig/UH)

Appendix B: Meeting Minutes from Technical Advisory Mid-Term Review Meeting on April 7th, 2015

Time: April 07, 2015 – 9:00 am to 12:00 pm

Location: University of Houston Energy Research Park

Present:

Craig Glennie, PI, UH

Hanadi Rifai, Co-PI, UH

Robert Marros, GTI

Andrew Hammerschmidt, GTI

TAC Members:

Peter Pedersen, Atmos Energy

Kyle Slaughter, Atmos Energy

Joe Berry, CenterPoint Energy

Mike Losawyer, Texas 811 (via conference call)

Regrets:

Gweneyette Broussard, Shell Pipeline Company LP

Joshua Rungee, LoneStar811

James Dillard, Entergy

Rick Daniel, Railroad Commission of Texas

Items of Note from Discussion

- Rob and Craig present progress to date, including results of initial pilot project tests carried out by both GTI and UH separately.
- Rick Daniel has recently (April 1st) left the Texas Railroad Commission. Joe Berry suggested David Ferguson as a potential replacement.
- James Dillard of Entergy has not responded to emails or phone calls. He has possibly left Entergy.

- Mike Losawyer suggests integrating one call tickets from TX811 into real-time display of excavator tracking on GTI GIS system to allow monitoring of excavator activity against open tickets. Mike will connect Robert Marros with Sarah Spears at TX811 to discuss implementation details
- Heath Consultants (http://heathus.com) suggested as possible commercialization partner. Andy Hammerschmidt will approach to gauge their interest.
- Additional hardware tests for UH prototypes planned with Centerpoint Energy for May/June timeframe. Craig and Joe to coordinate.
- Follow up conference call to discuss testing on Atmos Energy system in coordination with Texas811 one call center after Rob and Sarah discuss possible implementation modes.
- Final Conference Call for TAC will be held towards end of 2015 to present and discuss final results from project and progress toward commercialization.

Items for Follow-Up:

- Contact TX RRC to discuss potential replacement member on TAC for Rick Daniel (Craig/UH)
- Contact Heath Consultants to gauge interest in commercialization (Andy/GTI)
- Second field visit of UH team to Centerpoint Energy for testing, coordinate with Joe Berry (Craig/UH)
- Rob Marros to discuss integration of one-call tickets into GTI system with Sarah Spears at Texas811 (Rob/GTI)

<u>Follow Up Pilot Project Call – 06/17/2015</u>

Present:

Craig Glennie, PI, UH

Robert Marros, GTI

Andrew Hammerschmidt, GTI

Peter Pedersen, Atmos Energy

Kyle Slaughter, Atmos Energy

Joe Berry, CenterPoint Energy

Mike Losawyer, Texas 811

Items of Note from Discussion

- Rob Marros of GTI gave overview of discussion with Sarah Spears at Texas811 regarding implementation of active one-call tickets in GTI real-time display. Will be able to implement in time for testing in the fall.
- September set as best dates for full field testing of system
- Atmos will select a number of sites (2 to 3) and excavators (up to 5) in the Dallas Fort Worth and Houston areas. Will look to install on both crews installing new lines and repair crews.

Items for Follow-Up:

- Craig will follow up with Kyle and Pete to determine final dates and location of testing in September (Craig/UH)