Energy Research and Development Division

FINAL PROJECT REPORT

REAL-TIME ACTIVE PIPELINE INTEGRITY DETECTION SYSTEM FOR GAS PIPELINE SAFETY MONITORING

Prepared for: California Energy Commission
Prepared by: Acellent Technologies, Inc.

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PREFACE

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

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Real-time Active Pipeline Integrity Detection System for Gas Pipeline Safety Monitoring is the final report for the Real-time Active Pipeline Integrity Detection (RAPID) project (grant number PIR-12-013) conducted by Acellent Technologies, Inc. The information from this project contributes to the Energy Research and Development Division's Energy Systems Integration Program.

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ABSTRACT

The safety and security of the natural gas pipeline systems require real-time monitoring techniques. Currently available commercial technologies, however, are expensive, resulting in the need to develop a more cost-effective solution that can provide real-time and seamless inspection of damage and loss of structural integrity to ensure the safety of pipelines. This report suggests the Real-time Active Pipeline Integrity Detection (RAPID) system can be a cost-efficient statewide deployable inspection system for pipeline industries.

Acellent developed a built-in non-destructive inspection method called Real-time Active Pipeline Integrity Detection (RAPID) for detecting, locating, and monitoring the progression of pipeline damages. The system is based on an acoustic ultrasonic detection technology used in the Aerospace industry for detecting and monitoring damage to aircraft structures. Acellent finished the RAPID prototype development, made significant progress validating the system, and presented the system to both risk management companies and the gas pipeline industry, including Pacific Gas and Electric, Southern California Gas, and Chevron.

During this project, the RAPID system design requirements were established and tested with system integration and deployment. The deployed system has gone through the reliability testing in harsh environmental conditions. An in-field demonstration at Pacific Gas and Electric was performed. The RAPID system showed that it could detect damage locations and quantify the sizes of those damages in a real time. By the end of the project, economic benefit studies were performed, and the studies suggest that the annual loss of $30M due to the pipeline system failure can be avoided by adopting cost-effective inspection technology, which will enhance the safety of the natural gas pipeline system resulting in benefits to the ratepayers.

Successful deployment of the RAPID system in field applications has the potential benefits of reduced pipeline system failure and insures the safety of natural gas utility in the California.

Keywords: Real-time system, acoustic ultrasonic detection, safety, monitoring, gas pipelines, risk management

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EXECUTIVE SUMMARY

Introduction

The security and safety of California's natural gas system are important priorities, especially to prevent catastrophic pipeline failures that can result in death, injury, or destruction of property. Natural gas leakage also contributes to greenhouse gas emissions; methane specifically has 25 times more global warming potential than carbon dioxide.

The natural gas industry uses steel (metal) and plastic (non-metal) for construction of its distribution and transmission pipelines. Both materials are susceptible to aging and degradation processes. One of the leading causes of metallic pipeline failures is corrosion, however, in non-metallic pipes, cracking can cause gas leaks. Researchers are applying emerging nondestructive evaluation methods to detect impaired areas of a pipeline at risk from mechanical damage by degradation due to usage such as corrosion, erosion, and fatigue, environmental factors such as moisture and temperature variations, third party strikes, or natural events such as landslides, earthquake-induced liquefaction, or other ground movement. However, when such damage is located, the pipe must be exposed and inspected to determine if the damaged areas require repair or replacement. There is currently no reliable, built in, non-destructive method for determining if the damage is sufficient to have an effect on operational safety. Existing inspection techniques to detect pipeline damage requires the pipeline to shut off the gas flows during inspection resulting in the loss of revenue.

Project Purpose

Acellent developed a Real-time Active Pipeline Integrity Detection (RAPID) system, designed to be deployed on gas pipelines for detecting and monitoring corrosion, crack damage, and leaks. The embedded health monitoring technology at the core of the RAPID system was originated in the aerospace industry and is increasingly being evaluated by the pipeline industry as an alternative way of improving the safety and reliability of pipelines while reducing their operational cost.

Project Process

The development of the RAPID system included the following process steps:

1. Establish system requirements
2. Develop design of the system including the sensor network, and data acquisition hardware and software
3. Perform laboratory coupon and component testing to verify the system design
4. Develop the integrated RAPID system by integrating the local monitoring unit hardware/software with the remote monitoring site hardware/software for remote data management and processing
5. Perform in-field testing and demonstrations
6. Develop technology transfer and product readiness plans

Project Results

Acellent developed the RAPID system, deployed the system for field applications, validated the system by involving the end-user in the gas pipeline industry, and developed the technology transfer plan by working with the gas pipeline industry. The system was validated at PG&E in San Ramon, California. The results show the system to be reliable and effective for early detection of pipeline damage, and the technology is effective for in-field gas pipeline safety monitoring.

Project Benefits

The researchers found that the RAPID system can successfully provide significant benefits to pipeline operators to ensure the safety and security California's natural gas infrastructure, including expected reductions of pipeline system failure, lower maintenance costs and improvements of pipelines safety. The technology is a self-sufficient system for the noninvasive inspection of pipelines that will minimize the time and labor. The aim of this technology is not just to detect pipe failure, but also to provide an early indication of physical damage and enable monitoring of the progression of the damage. The early warning provided by a pipeline health monitoring system can then be used to identify remedial strategies before damage leads to a catastrophic failure.

CHAPTER 1: Introduction

1.1 Background

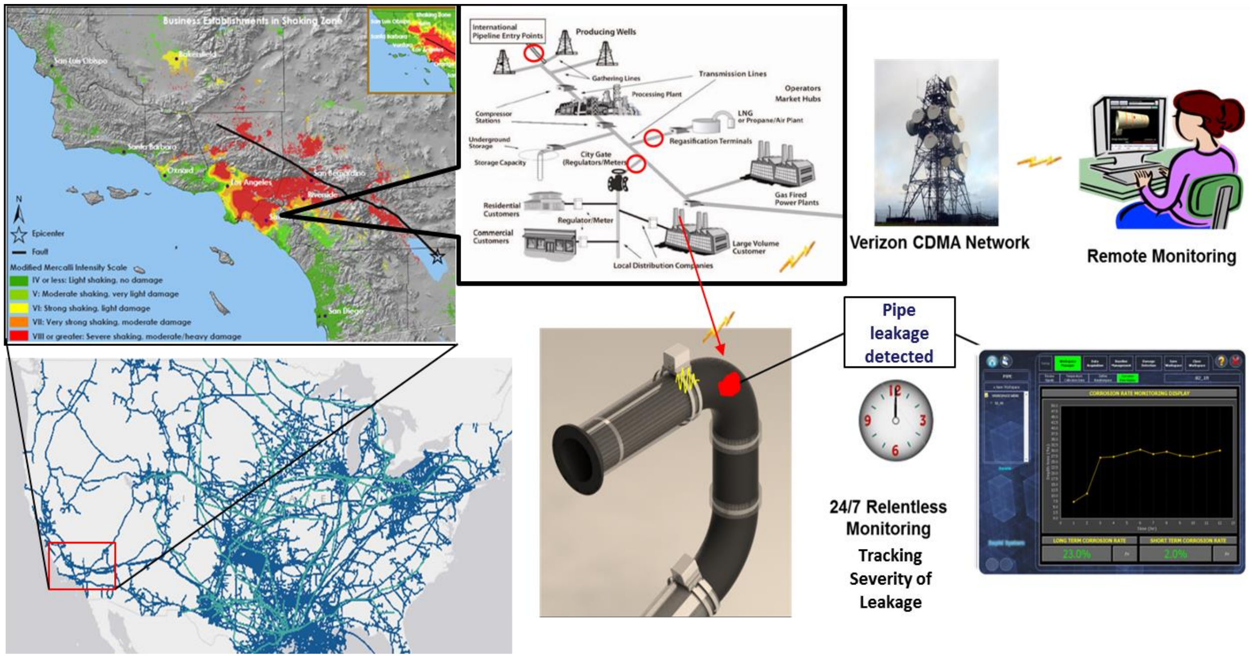
The natural gas pipeline industry consists of transmission and distribution companies. These pipeline systems can be simple or complicated. However, all gas pipeline companies are held to the same safety standards. Several different types of materials are used for natural gas pipelines. Gas service piping has been constructed primarily of steel (metal) and plastic (non-metal). Both metallic pipes and non-metallic pipelines are susceptible to aging and degradation processes. One of the leading causes of metallic pipeline failures is corrosion. However, in non-metallic pipes, the phenomenon of brittle-like cracking in plastic pipe relates to a part-through crack initiation in the pipe wall. This is followed by stable crack growth at stress levels much lower than the stress required for yielding, resulting in a very tight slit-like opening and a gas leak. There are a variety of nondestructive methods for locating areas of a pipeline that have suffered damage either by a third party or from natural events and degradation. When such damage is located however, the pipe must be exposed and inspected to determine if the extent of the damage requires replacement. Currently, there is no reliable, built-in nondestructive method for determining if the damage is sufficient to affect operational safety. Current inspection techniques require the pipeline to be shut down during inspection resulting in loss of revenue.

Structural health monitoring (SHM) is a new technology originating in the aerospace industrial environment and is increasingly being evaluated by the pipeline industry as an alternative method to improve the safety and reliability of pipeline structures and thereby reduce their operational cost. Significant benefits are expected for the aerospace and pipeline industries through the reduction of maintenance actions in-service and improvement of the operational efficiency. The core of the technology is a *self-sufficient* system for the continuous monitoring, inspection, and damage detection of structures with minimal labor involvement. The aim of the technology is not simply to detect structural failure, but also provide an early indication of physical damage. The early warning provided by an SHM system can then be used to define remedial strategies before the structural damage leads to catastrophic failure.

1.2 Project Goal

Acellent Technologies proposed the development of a ***"Real-time Active Pipeline Integrity Detection (RAPID) system for new and existing pipelines"*** for improvements in existing pipeline inspection technologies. The main goal of the project is to mature the technology for RAPID so that the system can be deployed to key hot spot areas in a gas pipeline infrastructure. The system will need to accurately measure damage such as a crack or corrosion damage in a pipeline in 24-7 manner. With mobile wireless communication, the data and real-time information is transmitted to a remote monitoring office. Below, the vision of RAPID system deployment is shown (Figure 1).

Figure 1: RAPID System for Natural Gas Pipeline Safety Monitoring



Source: Acellent Internal Document; Aggregation of USGS shakemap (www.usgs.gov), www.mapsearch.com Natural Gas Pipeline Coverage in USA.

1.3 Technical Objectives

In a two-year program, the product development of RAPID was developed as a main goal of this project. The following technical objectives were planned and completed:

- Worked with gas pipeline industry to identify the problem to solve and establish the requirements for building a solution system
- Conducted research and development activity to mature RAPID system for field deployment
- Verified system design and detection sensitivity in coupon level and laboratory environment
- Verified system reliability and performance
- Developed an easy-to-use inspection software
- Integrated system for field test
- Validated system performance in the field tests
- Developed the technology transfer strategy and prepare for mass production

1.4 Technical Tasks

Table 1 shows the list of tasks that addresses the technical objectives for this project:

Table 1: Technical Tasks for RAPID Development

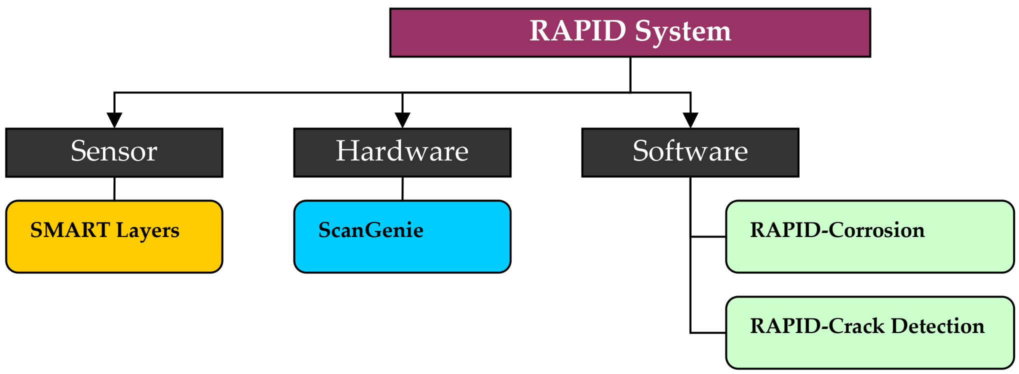
Task #	Task Name	Technical Objectives
1	Administration	To manage the project reports, meetings, requirements, and coordination with Energy Commission program manager to critical project review, tracking the monthly progress of the project, and resolution of subcontracting or any other administration matters.
2	Establishment of Requirements for RAPID System Design	To ensure the developed system can be implemented based on the end user's requirements and identification of design specifications.
3	Sensor Design, Optimization, and Packaging	To design an optimized sensor network based on the pipeline applications. The optimal diagnostic ultrasonic waveform will be chosen, the positions of sensors, and layouts and feasible detail circuitry design and protection mechanisms.
4	Hardware Development for Optimal Data Acquisition	To design hardware for maximum sensitivity of best data acquisition performance, reliable data storage, and transportation from the field to the data analysis center.
5	System Level Design and Integration	To address the implementation of sensors, hardware, and software into an integrated system. Work with the industry or utility to implement the practical system the industry or utility wishes.
6	System Reliability Issues	To address the reliability and tests on the integrated system to ensure the applicability and efficiency for the problem solutions.
7	Software Development	To develop the diagnostic software for monitoring, damage detection, and damage size estimation.
8	System Testing and Validation	To validate the developed system from Tasks 2-7 and demonstrated to the industry or utilities, to evaluate the system performance and applicability.
9	Technology Transfer Activities	To summarize technology experience, results, and lessons with end-users and decision makers of system acquisition. Develop the marketing strategies.
10	Product Readiness Plan	To lay out the system production plan for markets, in terms of marketing and sales projection, and implement detail plan for final production plan.

Source: Statement of Work in PIR-12-013 Grant.

CHAPTER 2:
Product Perspectives and Requirements

RAPID is an active structural health monitoring (SHM) system, designed for detection of pipeline corrosion and damage events. The system combines the SMART[1] Layers technology, ScanGenie hardware, and RAPID inspector's software in a whole system framework as shown in Figure 2.

Figure 2: RAPID System Organization Chart



Source: Acellent Internal Design Document

2.1 High Level Architecture (HLA)

The final design goals are for a RAPID system capable of:

- Having a deployable system for field environments with full installation of sensors, hardware, and an embedded communication modules and software.
- Creating remote site data management and analysis software.
- Detecting corrosion events (inside and outside the pipe) with required detection sensitivity and resolutions.
- Measuring the size and location of the event.
- Reporting critical damage events and distributing alarms or warning messages.

2.2 System Requirements

Figure 3 shows the requirements for the RAPID system broken down to three divisions: (1) Sensor, (2) Hardware, and (3) Software. The corresponding requirements for each division are illustrated.

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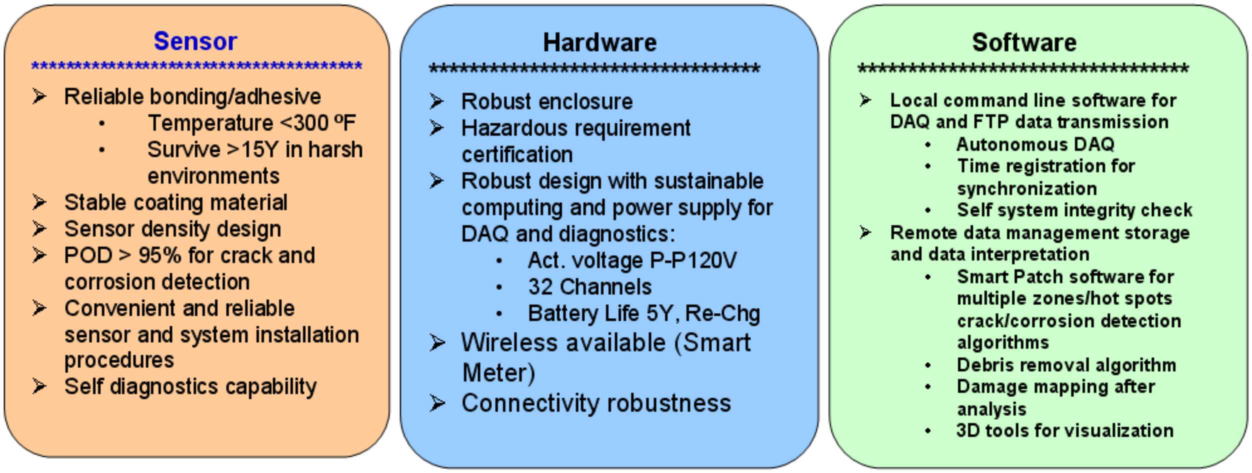
[1] SMART is the acronym of the Stanford Multi-Actuation and Receiving Transduction technology.

Figure 3: RAPID HLA and Requirements for Each Division



Source: Acellent Product Design Document

Sensors: the sensor system for RAPID is comprised of a group of piezoelectric transducers and receivers that establish an acoustic ultrasonic meshed network on the monitored pipeline structure. One of the system design requirements was that the sensor system needs to function continuously in the operational environment with peak temperature up to 300°F for 15 years or more. The sensor network needed to be coated and robust in this harsh service environment. The meshed sensor network was designed to provide a detection sensitivity of 95 percent Probability of Detection. Standard installation procedures and tools were developed and the implementation was verified through field-testing.

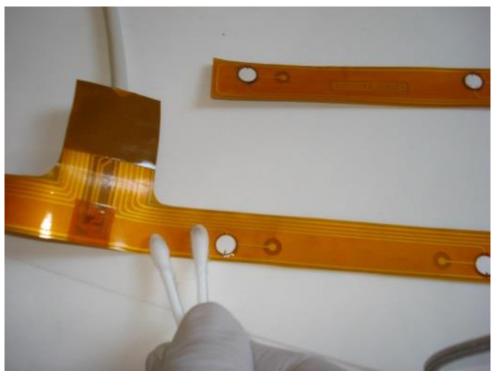
Hardware: the hardware will be bundled with the pipeline in the wild land operation environment, above ground and underground. The enclosure to package the in situ diagnostic system needs to be reliable and ruggedized in the hazardous environment. The wireless communication function will be in place to keep the connectivity of the system remotely from the office to the in situ.

Software: the RAPID software was designed to meet the following two requirements: (1) local command line software for in situ data acquisition and immediate diagnostics; (2) remote data analysis and storage software that will enable the system to provide advanced diagnostic information and alerts for decision makers or first responders if there are safety issues with regard to the pipeline facilities.

CHAPTER 3: Sensor Development

Sensor design is based on Acellent's SMART layer technology. The SMART layer is a thin dielectric carrier film containing a built-in distributed sensor network. The sensor is made of piezoelectric material-such as PZT[2], which can be worked as a transducer and receiver in Acellent's acoustic ultrasonic sensor network. The PZT is then embedded in the thin dielectric carrier film to become a smart layer as shown in Figure 4. The smart layer is flexible and easy to fit and mount on the curved surface of a pipeline. The mechanical strength of the film material is designed to resist both the environment and loading conditions for any pipeline in application.

Figure 4: Smart Layer Technology and PZT Sensors



Source: Photo provided by Franklin Li, 2014

3.1 Requirements for Sensors

Table 2 shows the smart layer sensor development requirements for RAPID.

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[2] PZT: Lead (chemical symbol Pb) Zirconium (Zr) Titanate (Ti) is an intermetallic inorganic compound with the chemical formula Pb $[Zr_xTi_{1-x}]\,O_3$ ($0 \le x \le 1$) and it is a ceramic perovskite material that shows a marked piezoelectric effect, which finds practical applications in the area of electro ceramics. It is a white solid that is insoluble in all solvents.

Table 2: Sensor Development Requirements

No	Sensor Requirement	Metric for Measurement of Success	Task to Evaluate Performance	Decision Points if not meeting requirement
1	Serviceability property	The thickness of layer is controlled within 40 mils. Sensor requires flexible and ductile enough for installation; tension strain requires up to 75% in the case of a 24-inch diameter pipe	Laboratory to verify static tension test	Laminate additional retrofit layer inside layer without relaxing thickness requirement
2	Durability	The bonding agent (adhesive) and composite wrap material required to hold down the sensor during the fatigue loading cycles do not debond even after the pipe material fatigues	No test is required. ASTM reference can approve the life for 20 years.	N/a.
3	Detect-ability	1) damage simulator detection using 0.5”, 1”, 2” etc. diameter energy absorption pad 2) real damage detection using dremel tool to grind off an area of the pipe surface, 1 in. sq., 4 in. sq. etc.	Verify the detection percentage at several spots; increase/ reduce the number of sensors and layout spacing	Determine the final sensor spacing design for input of sensor manufacturing
4	Protection	Chemically neutral coating materials for covering sensors. PG&E has suggested the suitable material.	Verification in lab. Refer to ASTM test results and verify if needed.	Down select the best material for protection
5	Installation	Easy to install. Tooling and standard procedure in place.	Verify the installation in the PG&E test filed	Several iteration of exercise may apply for validation

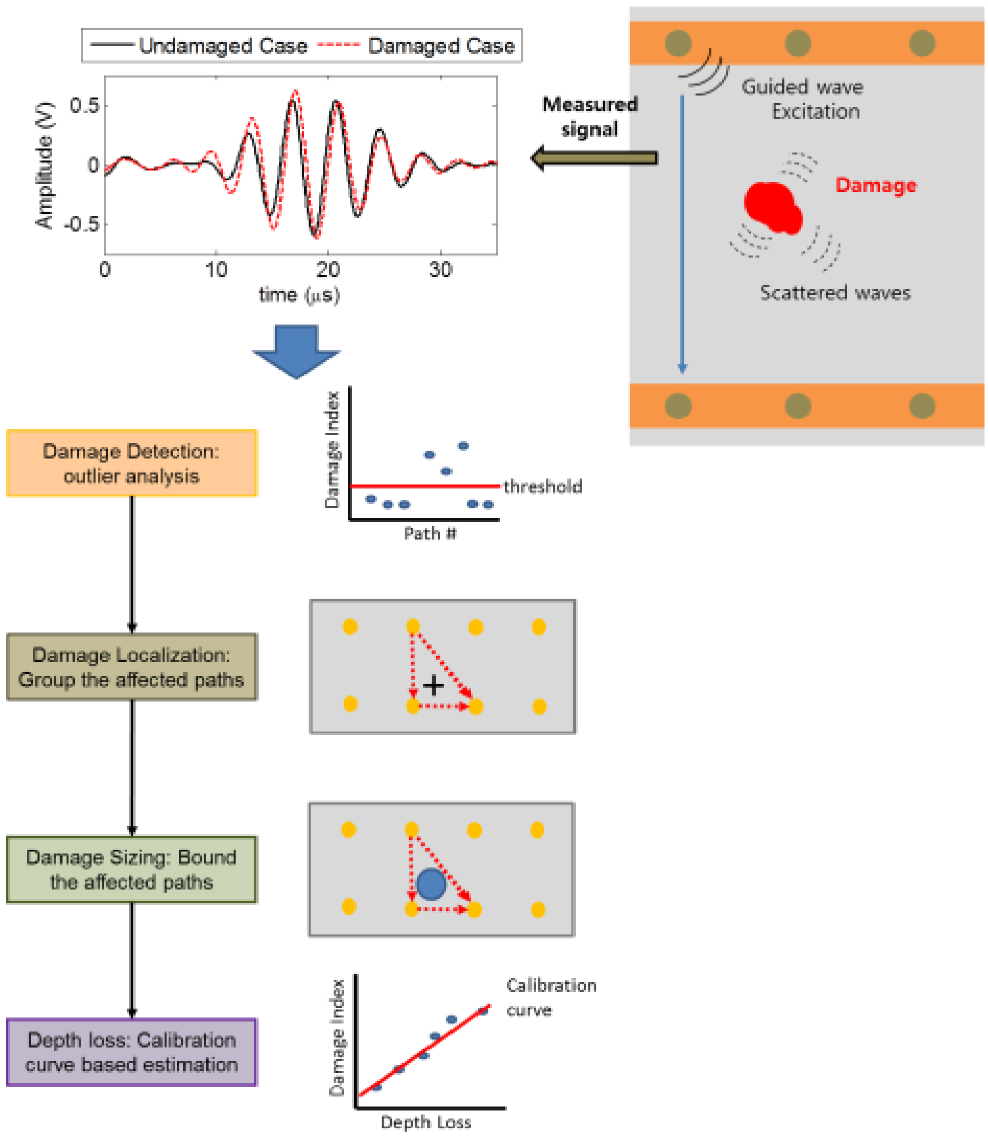
Source: RAPID System- Sensor Development Requirement Report in 2014

3.2 Optimal Sensor Design

The sensor system operates based on Lamb-wave ultrasonic propagation theory. Figure 5 illustrates the damage detection theory used in the RAPID system. In the system, the sensor layout and their coordinates and actuation signal properties are required to be determined before it can work. The following actuation signal properties must be determined to optimize the sensor network design: (1) the wave form to be generated from the hardware; (2) the input voltage to drive the wave form generation; (3) the sampling rate for data acquisition; (4) the amplification number (in db gain) for signal tuning in data acquisition; (5) number of data points to be sampled in a wave form signal data.

Acellent has developed a computer code for determination of how many sensors need to be installed to achieve the desired detection sensitivity. The Spectral Element Modeling[3] software was used to simulate the waveform generation for the designed sensor layout. The program does the numerical analysis based on Lamb-wave propagation theory to verify whether or not the number of sensors in a smart layer design is sufficient to detect the damage event, measure the size, and find the location.

Figure 5: Damage Detection Theory in RAPID system



Source: Illustration from the RAPID interim Software Development Report, 2014.

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[3] Spectral Element Modeling software refers to Stanford Structural Laboratory release tool for analyzing the wave field response from PZTs.

3.3 Sensor Protection

PG&E introduced the fiberglass-based composite wrap material to Acellent. The materials are currently used for the retrofit of existing pipeline systems. A review of the material properties and references from ASME AARP A4.1 was completed. It was determined that the application of the same wrap material on the pipeline can provide sufficient and robust protection for the sensor layer installed on the metal pipe. This protection method will ensure a sensor service life on the pipeline for the required 20-year life cycle.

CHAPTER 4:
Hardware Development

The hardware design for RAPID was based on Acellent's ScanGenie Technology. The ScanGenie hardware was developed by Acellent for application to its structural health monitoring systems. The hardware was used to drive the multiplexing, actuating, and receiving acoustic ultrasonic signals from the piezoelectric sensors. The hardware also has the capability of measuring temperature from connected thermal couples embedded in the SMART Layer.

In order to meet the development goal of this program and to make RAPID a mature technology for gas pipeline application, Acellent had to improve the ScanGenie technology to make the system more robust and more miniaturized in size. Therefore, the following requirements were set for the hardware design:

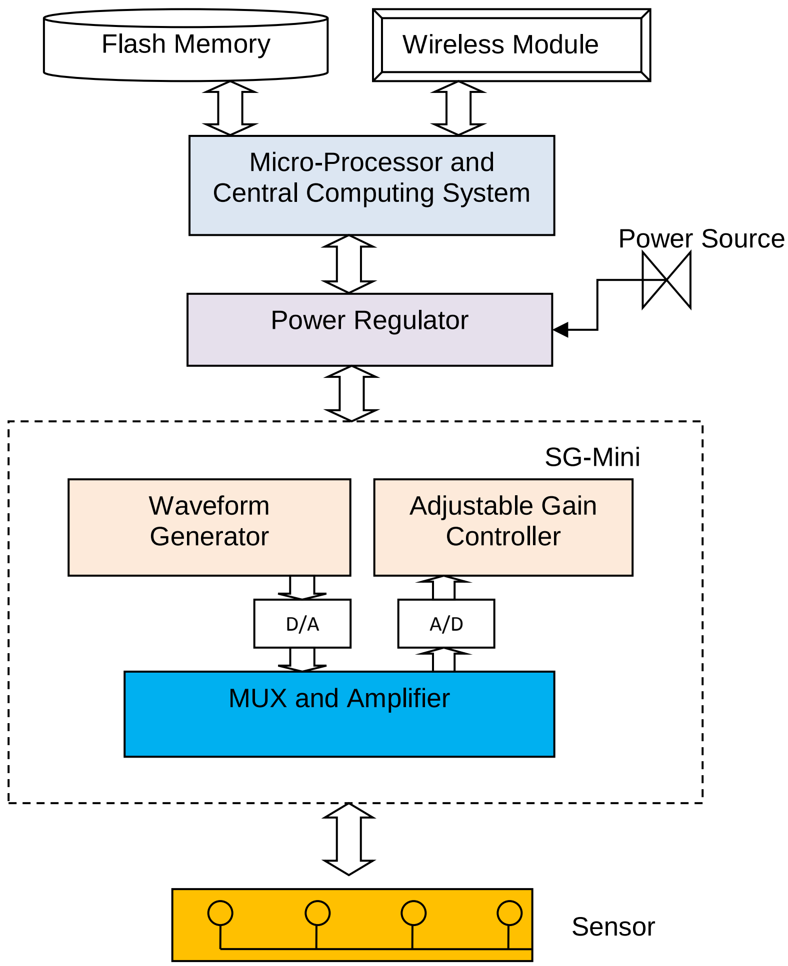
- An integrated and robust computing and diagnostic system
- Robust power regulator for 24 hours a day, 7 days a week service
- Extensive solid-state computing circuits and flash memory system that can be environmentally robust
- Both wired and wireless-radio communication modules available and efficient for data communication and diagnostic message distribution
- Enclosure to be environmentally robust and meet the standard of NEMA[4] Type 4.

4.1 Hardware Architecture

Figure 6 illustrates the block diagram for the hardware design. The new hardware architecture is called SG-mini system, which is in form factor a compact and just-fit-sized electronic, memory, and wireless module system for future in-field applications.

[4] NEMA- National Electrical Manufacturing Association standard for electrical instrument and enclosing design

Figure 6: Block Diagram of Hardware Architecture Design



Source: Acellent Interim Report of RAPID Hardware Development, printed in 2014

4.2 Hardware Requirements

The hardware is featured with the following specifications:

1. A network of up to 32 sensors is to be used in a single monitored section. The hardware must be designed to be able to support 32 channels; the solution is to use a 37-pin connector to support this requirement

2. Strong signals need to be propagated from an actuation sensor to a receiving sensor. The hardware must be designed to provide a peak-to-peak amplitude of up to 90 Volts and the sensor signal receiver must have a tunable Voltage Generation Control (VGC) gain of 20~60dB.

3. Based on the typical sensor spacing used, the time window for the signals to be analyzed is within the 1000 microsecond range. The hardware must be designed to have an

Analog-to-Digital Convertor with a sampling rate of up to 48 Mega Samples per second, and capture up to 16,000 samples.

4. Based on coupon tests, the best transmission signals for analysis are "burst5" signals with a frequency range of 200 KHz to 350 KHz. The hardware must be designed to send out acoustic signals from within this frequency range. Hardware must have an arbitrary waveform generator that can generate these types of signals.

5. Based on the ideal signals transmitted, the receiving end of the hardware must be able to receive the signal within this frequency range. The hardware must also be designed with low-pass and high-pass filters to filter out any noise outside the desired frequency range.

6. The sensor network would work best if both through transmission mode and pulse echo mode are supported. The hardware must be designed to handle both through transmission mode and pulse-echo mode by designing the signal generation and data acquisition portions of the hardware to support these options.

7. The hardware must be designed to support sensor diagnostics.

8. As the structure is exposed to varying temperatures, temperature compensation will be required during analysis. Therefore, a temperature sensor needs to be included in the sensor network. The hardware must be designed to be able to acquire data from a temperature sensor. This sensor will be allocated enough pins to be supported on the 37-pin connector.

9. The hardware set must be able to collect and store data while being accessed remotely. The hardware must be designed to be able to initiate independent data collection and store the resulting data. Hardware must be designed with a processing unit such as a single board computer to support this capability.

10. The hardware must have reasonable size and weight to be used as an on-site/on-board unit.

Table 3 shows the summary of requirements and the corresponding design specifications for hardware:

Table 3: Hardware Requirements and Designed Specifications

No	Hardware Requirement	Designed Specifications	Proposed Task of Verification	Strategic point
1	No of sensor channel	AS32/T1	32 PZT + 1 Temp	No risk
2	Optimal signal to noise ratio	90V Peak-to-Peak (P-P); 20~60dB	Apply the 90V P-P actuation signal and receive the adjustable VGC Gain in the 20~59dB range.	Additional high voltage device may be required if designed signal amplitude is not satisfied

			Test verification required	
3	Sensing time window	1 ms ~6 ms	Sampling rate: 12~48Mhz Samples: 4,000~16,000	No risk
4	Signal type and Frequency	At least 5 peak sinusoidal pulse wave form (BURST); scanning frequency in 200~350kHz	BURST 5, and BURST 10 available. Verification of scanning frequencies and wave form is required	Down select the optimal wave form and driving frequency according to the structure
5	Signal filter	Low-pass (LP), high-pass (HP) and band-pass (BP) filters. Minimum RMS (<5%) of repeated signals would apply	LP, HP, and BP with the central frequency ±100kHz are required. Verification is required	LP and HP may not be required if BP can fully take care of signal noises
6	Transmission modes of sensor network	Pulse-echo and Pitch-catch modes	Will verify with both modes.	Both transmission modes may apply
7	Sensor diagnostics	Apply impedance measurement	Measure impedance and set up the safe/fail threshold	No risk
8	Temperature measurement	Temperature sensor measurement available	Apply external thermal sensor for temperature measurement calibration	No risk
9	Data structure and management	Multiple sensor channel signals can be structured in a single file	Mathworks Mat-Binary Level 5 data format is currently proposed	Will verify the end-user human machine interface to finalize the data format, no risk
10	Size and Weight	120x120 mm for each piece of PCBs; less than 8 oz. for each PCB	Verify the footprint of PCB is sufficient for loading all the electronic devices	No risk
11	Mechanical Package	The package has to survive humidity, seismic vibration in fixtures, and expected third party impact loads	The package integrated with PCBs will undergo functional testing in the lab with tests of environment conditions and vibration loads	Robust design is a must
12	Communication System	Capability of remote access and data retrieval from systems in rural locations with minimal existing infrastructure	Utilize 3G/4G LTE wireless broadband connections	Requires contract with cellular provider to data plan and hardware, requires secure communication scheme

Source: Acellent Interim Report of RAPID Hardware Development, printed in 2014

CHAPTER 5: Software Development

Based on past experience with pipeline coupon tests, the following specifications must be met for the software to be used in the RAPID system:

1. Easy to operate, intuitive graphical user interface (GUI). The purpose of the GUI is to transmit the information provided by the damage detection system in the simplest manner possible to aid understanding and minimize the learning curve required to utilize the system.
2. Robust, reliable remote data acquisition, management, and transmission software must be implemented to allow the user to retrieve data by command (user initiated) or automatically (system initiated). The software should require little to no user interface and be self-configuring to the largest extent possible. The system should be designed to minimize the likelihood of data transmission failure and should fail gracefully in cases where data transmission fails.
3. Accurate, flexible damage detection algorithms. Based on previous tests performed on pipeline coupons the damage detection algorithms utilized by Acellent provide a strong base upon to build the RAPID damage detection algorithms. The modified algorithms must be designed to provide accurate information on damage occurrence, location, and size (both surface area and depth) while minimizing the occurrence of false positive or negative detections.

Table 4 shows the summary of requirements and corresponding design specifications.

Table 4: Software Requirements and Designed Specifications

No.	Requirement	Designed Specifications	Proposed Task of Verification	Strategic Point
1	Human machine interface	Easy to operate One or maximum two shell graphical user interface (GUI) turned page for operation; terminal control interface for on-site system operation is required; Tablet operation requirements for the remote side software	Will verify with PG&E technician and evaluate the acceptance or rejection by the technicians	Several iterations of validation may apply
2	Software installation and removal	The executables and library functions will be packed into an installation package; zipped form for Windows installation	Verify by variable system	No risk

3	System and sensor integrity check function	Provide one button for sensor and hardware-software integrity check	Verify by using variable scenario of system break-downs	No risk
4	Automated data collection	The system software can be programmed and do data collection by timer (schedule)	Verify timer function is programmed	No risk
5	data management	In situ system storage monitoring software is required	Data size/number monitoring is required for in situ system data storage management; outdated baseline data files should be removed automatically by system or admin decision	No risk
6	Remote system software data log updates	The remote system software should look up the data folder and verify if there is new data coming to the remote data server	Data log should be updated by timer trigger or data collection incidence trigger.	No risk
7	Diagnostic Workspace Setup	Diagnostic software requires systematic setup function to define its workspace, actuation conditions, and sensor network definition. The software should allow multiple workspaces setup in a pipeline system network for monitoring additional hot spots in one pipeline system.	One workspace is comprised of multiple hot spots in the monitoring software system.	No risk
8	Diagnostic Hardware Sensor Actuation Parameter	The diagnostic actuation parameters are formatted systematically for ease of changes and updates.	Diagnostic setup is allowed in the software system	No risk
9	Corrosion Detection	Diagnostic software for corrosion detection covers: (1) environmental compensation; (2) sensor signal detection index measurement; (3) detection and localization of damage areas; (4) quantification of the size of damage areas.	The detection algorithm is validated in the real pipeline coupon tests. The sensitivity is verified using both damage simulator and real damage approach.	No risk

10	Crack Detection	Diagnostic software for crack detection covers: (1) environmental compensation; (2) sensor signal detection index measurement; (3) detection and localization of the crack; (4) quantification of the size of crack depth in its boundary.	The detection algorithm is validated in the real pipeline coupon tests. The sensitivity is verified using both damage simulator and real damage approach.	No risk
10	Detection Report	Diagnostic report is formatted and displayed in the human machine interface	Report function is programmed	No risk
11	Baseline data management	The software is required to sort and accept/reject the baseline data automatically. Due to the incident failure of hardware, the data may lose the integrity, therefore, the system is required to manage baseline automatically.	Auto-Baseline management software is programmed and will be tested for a long run case study.	No risk
12	Data Integrity check	The system is required to inspect the data integrity to minimize the system down time due to data integrity loss.	Due to the complexity of systems (in situ and remote), the data integrity check function is programmed	No risk
13	Data porting	Import and Export Function Required	Workspace files and data can be packed and go (deploy) to different analysis station with ease	No risk
14	Result Visualization 2D	Applicable 2D visualization of detection result	2D presentation will be programmed for results	No risk
15	Result Visualization 3D	Applicable 3D visualization of detection result	3D viewer and detection visualization tool will be programmed	No risk
16	Admin and User Control	Software requires user and admin shells in case of management of hard system configuration files	User login window will be programmed to distinguish the user and admin shells	No risk
17	Communication port	Software will provide an interface to set up applicable communication port for data transmission	Wireless communication code and configuration interface	No risk

Source: Acellent Interim Report of RAPID Software Development, printed in 2015

CHAPTER 6:
System Integration

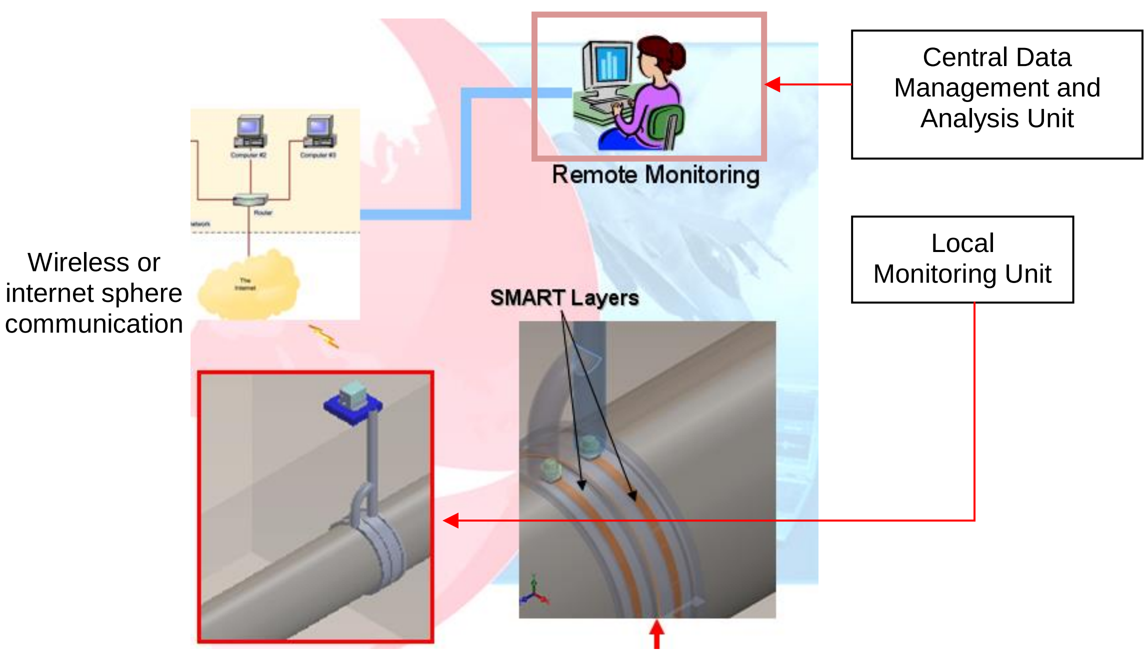
6.1 Implementation and System Sectors

RAPID is an active structural health monitoring (SHM) system designed for pipeline monitoring. The final goal functionalities of the system are:

- Deployable system for rural environments with full installation of sensors, hardware and communications (software)
- Remote site data management and analysis functions
- Detect corrosion events and locate the event positions
- Measure the size of the corrosion events
- Detect crack events caused from internal or external sources
- Detection the size of the crack
- Send alert messages to a remote center

The pipeline to be monitored is usually located at a remote distance from the center of data management and analysis. Therefore, the integration of system can be divided into two sectors in a RAPID system as shown in Figure 7. Sector 1 is the RAPID local monitoring unit, and Section 2 is the Central Data Management and Analysis center.

Figure 7: System Integration

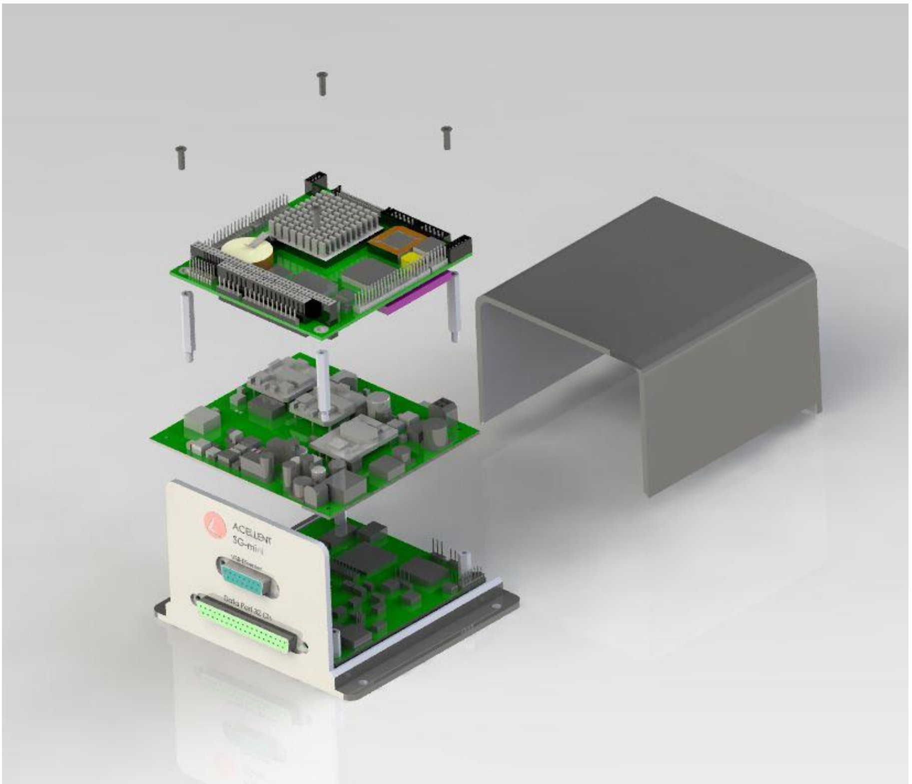


Source: Acellent internal document

6.1.1 Local Monitoring Unit

The local monitoring unit is comprised of the electrical devices and SMART layer sensors network The SMART layer sensor network is mounted on the surface of a pipeline and wired to the local inspection hardware unit, which is an integrated device box that encloses a single computer board, power regulator, and ScanGenie-mini device as shown in Figure 8.

Figure 8: Local Monitoring Unit in Explosive View of 3D Model



Source: Acellent Interim Report of RAPID Hardware Development, printed in 2014

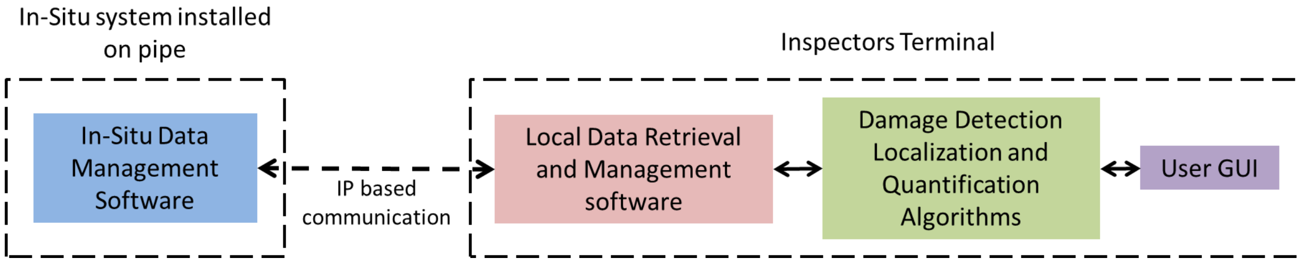
6.1.2 Central Data Management

The current central data management computer is a dedicated personal computer connected via the internet network. The software for the central data management unit to communicate with the local monitoring units was developed in this program.

6.2 System Integration

Figure 9 shows the high-level architecture of the integrated RAPID system. The software that has been implemented at the system level includes: (1) in situ data collection and management software, and (2) Graphic User Interface (GUI)-based RAPID inspector terminal software. As shown in Figure 10, the GUI-based RAPID inspector terminal software is composed of the local data retrieval and data management module, damage detection algorithms, and result/report presentation GUI.

Figure 9: High Level Architecture of Integrated RAPID System



6.2.1 Operation System in the Local Monitoring Unit

Currently, the in situ local monitoring unit uses Windows XP mobile for the operation system. In the future, Linux may be used for the local monitoring unit. Also included in the local monitoring unit are the acoustic ultrasonic signal actuation, data acquisition, temperature data acquisition, and user datagram protocol, that is, UDP[5] terminal communication protocol software.

6.2.2 Operation System Requirement for the Central Data Management

The central data management unit is usually a Windows Operating System. There is no specific operation system requirement except for the requirement of an internet communication protocol to support UDP. Acellent's RAPID Inspector software is made of Java standard environment (Java -SE) technology. The software system is deployable to any Windows framework with the installation of the Java run-time environment.

Figure 10 illustrates the current software development result and the presentation of data in the graphical user interface (GUI).

6.2.3 Data Management and Retrieval Software

One of the key attributes of the RAPID system is its ability to monitor a pipeline on a continuous 24/7 basis. This functionality is enabled by the placement of in situ hardware at the sensor installation site to generate and digitize the waveform data combined with a remote user terminal that can be located at any user-defined location. These two geographically isolated components are linked together utilizing standard internet communication technologies to allow the transfer of data between the two components. For RAPID, the system must be capable of operating in remote locations where fixed internet access may not be available. As a result, the initial prototype utilized a connection via the Verizon 4G wireless network to enable the system to be installed at any location a wireless internet connection is available. As such, the final architecture includes the use of in situ hardware and data management software in

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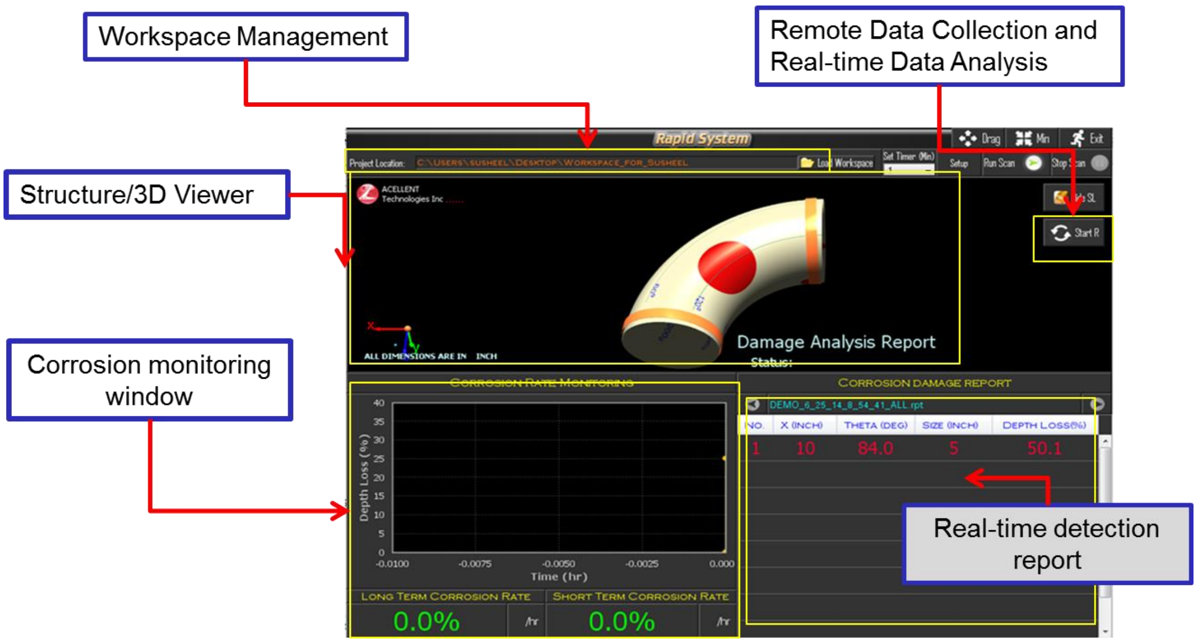
[5] UDP: User Datagram Protocol is a communications protocol that offers a limited amount of service when messages are exchanged between computers in a network that uses the Internet Protocol (IP). UDP is an alternative to the Transmission Control Protocol and, together with IP, is sometimes referred to as UDP/IP.

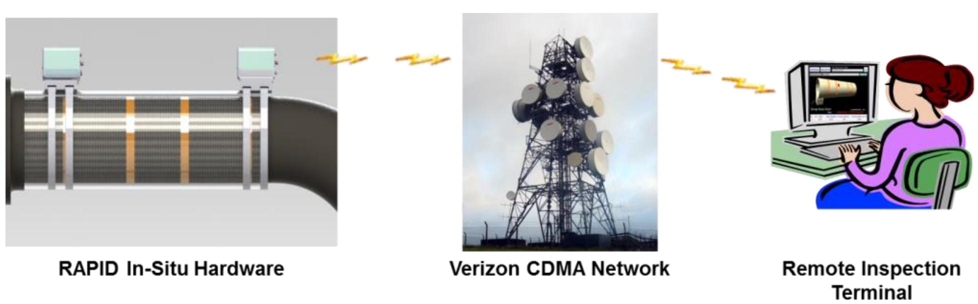
conjunction with a remote user interface connected together by an internet backbone carried over the Verizon network. An overview of this arrangement can be seen in Figure 11.

Figure 10: Inspector Software GUI in RAPID system



Source: Software RAPID User's Manual

Figure 11: Overview Operational Environment



Source: Acellent internal document

The system operates on a standard internet client-server model where the in situ hardware acts as an internet based server that is interrogated by the inspection client. This ensures that the in situ hardware can be remotely accessed from a remote inspection system located at any location world-wide. In this model the RAPID in situ hardware operates as a remote server that can be interrogated at any time by the inspection terminal software which acts as a client. In this manner, the user can check on the integrity of the pipe, the status of the installed in situ hardware, the integrity of the sensors, and update the data collection parameters at any time providing "24 hours a day and 7 days a week" (24/7) near real-time remote monitoring of the pipeline.

CHAPTER 7: In-field Tests and Demonstration

7.1 In-field Demonstration and Test Setup

With the completion of the lab tests, a major test of the prototype system was performed on a test loop located at the PG&E ATS center. This test utilized a fully functional remotely accessible RAPID hardware unit installed on a one-foot section of the test loop with remote data acquisition capabilities provided by a 4G wireless gateway. The test was split into three parts. In the first part of the test, a damage case was installed by PG&E under the supervision of Acellent personnel. The purpose of this initial test was to validate the functionality of the RAPID hardware and ensure the system was running properly. After the initial installation, in the second part of the test, a pair of blind tests was performed on the pipe section. The first blind test was structured as a live demonstration of the RAPID system for PG&E and Energy Commission personnel with Acellent knowing that the damage would occur but not knowing where or how large the damage would be. The second blind test was a more thorough exercise of the RAPID system where damage was placed on the pipe section by PG&E without any input from Acellent personnel over a period of three months while data was collected remotely. At the end of the data collection period for the third part of the test, Acellent personnel aggregated the data and then provided a summary report detailing where RAPID had detected damage, how large it was estimated to have been and when it is estimated to have emerged.

7.1.1 Prototype Installation Validation

Immediately after installation and setup of the prototype RAPID system, a pair of damages was installed on the test loop by PG&E personnel under the supervision of Acellent personnel. The purpose of this test was twofold. First, the test was performed to ensure that the RAPID prototype would perform as expected in the field. Second, the test was conducted to ensure that the RAPID system would be capable of detecting and quantifying the type of damage being installed by PG&E. This was a necessary step as PG&E utilized a plasma gouging technique to create a damage type that was a much closer simulation of true corrosion than had previously been tested. To this end, the damage cases installed for this test were of two types. The first damage case installed was created as a two to three inch diameter area of damage with a maximum depth of 10-20 percent of the total wall thickness. This damage was designed so that it should be easily detectable by the RAPID system and ensure the proper functioning of the system. The second damage installed was similar in diameter but with a maximum depth of approximately 10 percent wall thickness loss. Based on previous research, the RAPID system was predicted to detect the first, larger damage while it would not detect the second smaller damage. The reason these two damage cases were performed was to determine if there had been a significant change in the sensitivity of the RAPID system to corrosion type damage based on the new simulated corrosion type.

After installation of the damage, the RAPID system was used to attempt to detect the damage on the pipeline. For this test case the RAPID system accurately detected the larger of the two damages installed on the pipe but did not detect the smaller damage. Based on previous testing this was the result expected by Acellent personnel and helped to validate the capabilities of the prototype system. An overview of the results can be seen in Table 5 while examples of the damage installed by PG&E can be seen in Figure 12.

Table 5: Summary of Initial Damage Installed by PG&E

	Location		Quantification	
	x (in)	Theta (deg)	Diameter (in)	Depth (% Wall Thickness
Damage Installed by PG&E	6	200	2	10%
	6	310	2.75	14.7%
RAPID Estimate of Pipeline Damage	8.224	313	2.62	13%

Figure 12: Examples of Damage Created in Blind Tests

(a) (b)

Source: Image taken by Pacific Gas and Electric in blind tests

7.1.2 Live Demonstration of RAPID

After completion of the system setup and initial testing, a live demonstration of the system capabilities was performed at the PG&E Advanced Technologies Services (ATS) center by Acellent for PG&E and the California Energy Commission on June 6, 2014. This demonstration consisted of an overview of the RAPID system followed by a demonstration of the ability of the RAPID system to detect new damage and changes to existing damage on the pipe. For this demonstration, PG&E created one new damage area and deepened one of the original damage areas in the monitored portion of the test loop. After the damage was created, Acellent personnel used a hand-held tablet PC to operate the RAPID system. For this demonstration, the RAPID system was operated remotely from the tablet PC over a wireless link and the results displayed on a damage detection GUI projected onto a large screen TV for the audience. The purpose of this test was to demonstrate the near real-time capabilities of the RAPID system to provide information on damage in pipelines. During this test, the RAPID system successfully detected the increase in depth of the initial damage as well as detecting the appearance of a new damage area. The system managed to localize both damages and provided an estimate of 25 percent maximum wall thickness loss in the damage region. A later laser scan of the area showed that the actual maximum wall thickness loss had been approximately 28 percent. This demonstration showed that the RAPID system could accurately detect and size damage in near real-time providing fast updates on pipeline condition to pipeline inspectors and managers. Pictures showing the test layout for the demonstration can be seen in Figures 13-16.

Figure 13: Demonstration Area at PG&E ATS

Source: Photo by Acellent on June 5, 2014.

Figure 14: Acellent Personnel Controlling RAPID System with a Tablet Computer

Source: Photo by Acellent on June 5, 2014.

Figure 15: RAPID Damage Detection GUI on a TV Monitor

Source: Photo by Acellent on June 5, 2014.

Figure 16: RAPID Prototype System Mounted on a Pipe

Source: Photo by Acellent on June 5, 2014.

7.2 Blind Testing of RAPID Field Prototype

After the live demonstration performed by Acellent on June 6th the RAPID prototype system was utilized as part of a blind field test through September 30th. For this test, PG&E personnel were allowed to place damage at any location and of any size on the monitored area of the pipe while Acellent personnel remotely monitored the pipe from their offices in Sunnyvale, California. Furthermore, data collection was only performed in the evenings to ensure that any work performed on the pipe by PG&E did not cause a spike in the RAPID data that might be used to estimate when new damage occurred. During this period, no physical inspections of the pipe for damage were performed by Acellent personnel. At the end of the monitoring period, Acellent personnel created a brief summary of the results of the test detailing where the RAPID system had detected damage on the pipe, how large the damage was estimated to be and at what time the damage had occurred.

7.3 System Setup and Calibration

During the field testing of the RAPID system a total of 118 days' worth of data were collected by the remote RAPID software and uploaded to a monitoring server at the Acellent headquarters in Sunnyvale, California. This data was received as a series of discrete sets of data with each set representing a single scan of the monitored area. Each scan was further divided into a series of ultrasonic wave propagation tests from a single actuator to a single sensor known as a path. These scans were performed once an hour during each evening from 6:00 p.m. until 6:00 a.m. the previous day. Each discrete data set was analyzed by the damage detection software and a report on the number of instances of damage detected and their estimated location, size, and depth were created. Each individual result was then aggregated into an overall report providing information on when the damage had emerged and how damage on the pipe segment had changed over time.

After installation but prior to operation, the RAPID system must be tested and calibrated to ensure proper operation of the system. This is a largely automated process with two primary portions. The first is the calibration of the data acquisition system to ensure the proper propagation and digitization of the waveforms. The purpose of this portion of the signal analysis is to ensure that the waveforms being collected and analyzed are neither saturating the digitization hardware or being drowned out by analog noise either case of which would make the data unusable.

In the second portion, once the system has analyzed and optimized the data, a series of baseline data sets are taken. These baseline data sets serve as a reference pool of signals against which all of the future data is compared to determine whether damage is present. The baseline was collected over the course of three days to ensure that the reference data includes a wide range of environmental conditions to minimize any effect from temperature swings or other environmental changes. Once a baseline pool had been established, the system became operational and began monitoring the pipeline for damage.

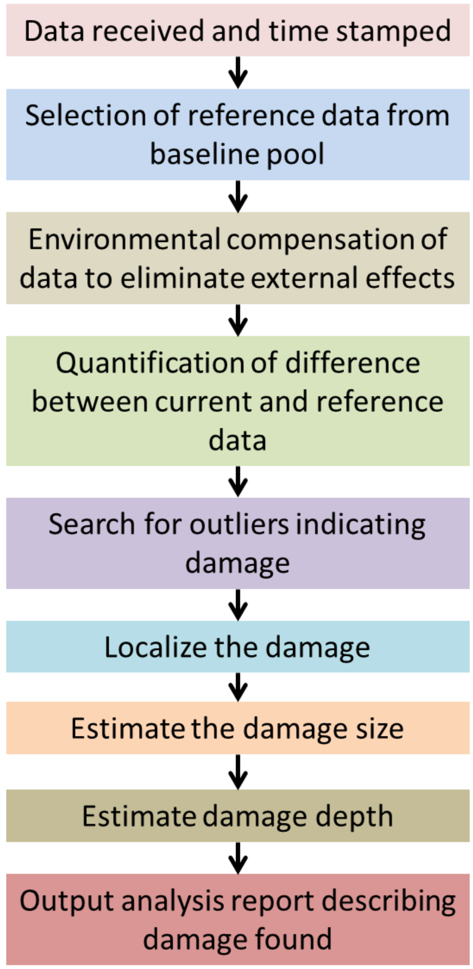
7.4 Analysis of Individual Damage Scans

In order to detect damage, the RAPID hardware would periodically scan the pipeline using ultrasonic guided lamb-wave signals. The resulting raw data from these scans would be transmitted to a server located at Acellent Technologies where the data would be time-stamped and stored. The data would then be compared to the baseline data pool from which a reference data set is selected. This reference data set is then processed with environmental compensation algorithms that use signal correction techniques to reduce the effects of temperature and other environmental parameters on the damage detection algorithms.

Once the baseline reference has been selected and preprocessed, the current data and reference data are directly compared with the difference between the current and reference data being calculated separately for each path with the resulting difference being encapsulated in a non-dimensional parameter. The resulting series of non-dimensional parameters is then searched for any outliers. The presence of outliers is used as an indicator of damage in the structure as the outliers only occur when a significant change to the signal has occurred which are in turn caused by structural changes that interact with the wave propagation. If no outliers are found then the structure is undamaged and this is reported. If outliers are detected, the path associated with that outlier parameter is classified as a damage path and the RAPID algorithms attempt to localize and quantify the damage.

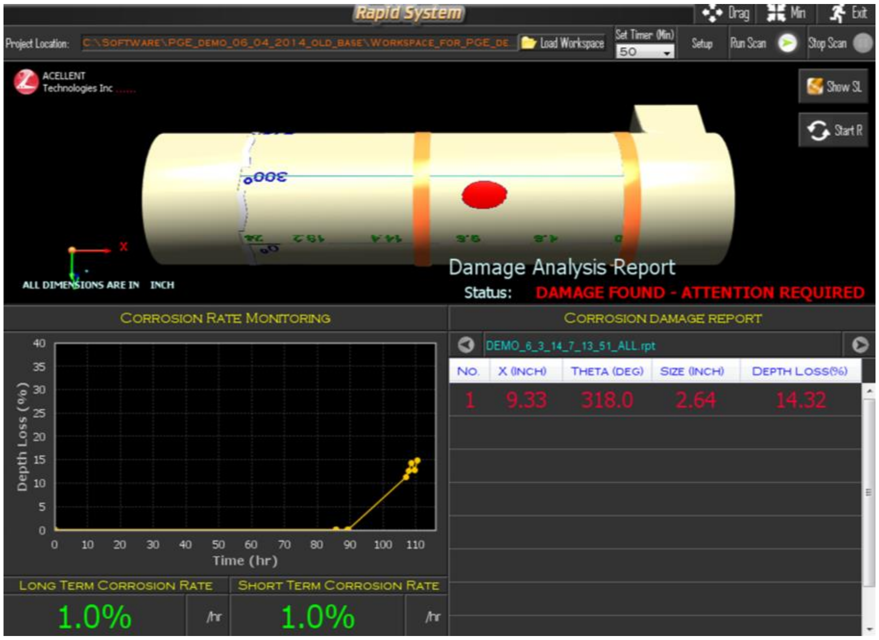
Damage localization and quantification is attempted by the RAPID system when significant differences between the current and reference data are detected. In these cases, a series of physics and geometry-based algorithms are used to analyze the data to estimate the physical location where the change occurred. These algorithms are assisted by the path dependent nature of the data. Since each signal is associated with the actuator-sensor pair between which it was propagated any damage that would cause significant change in that signal can be assumed to have occurred on or near the geometric path connecting the sensor to the actuator. Based on the combination of paths for which the signal was found to have changed significantly, the location of any damage regions can be estimated with undamaged paths being used to set the boundaries of the damage region. Once the location of the damaged region has been identified, the algorithm calculates a damage size estimate based on the geometric distribution of damage paths within the region. Finally, the degree of change in the paths associated with each damage region is compared to a known reference for the degree of change induced by a given amount of wall thickness loss. This method allows the system to estimate the depth from the physics response of the waveforms to the damage. Once the damage has been localized and quantified the RAPID software generates a report detailing the results of the data analysis including the time at which the data used to generate the report was collected, the number of damage areas found, and the location, size, and depth of each damage area. This report is then stored and can be displayed in the RAPID GUI software. A flowchart detailing the steps of the damage detection algorithm can be seen in Figure 17. An example of the damage detection results as reported by the GUI can be seen in Figure 18. This process is repeated each time a scan is taken of the pipe.

Figure 17: Flowchart of Damage Detection Process



Source: Acellent RAPID Design Document

Figure 18: Example of the Damage Detection Result



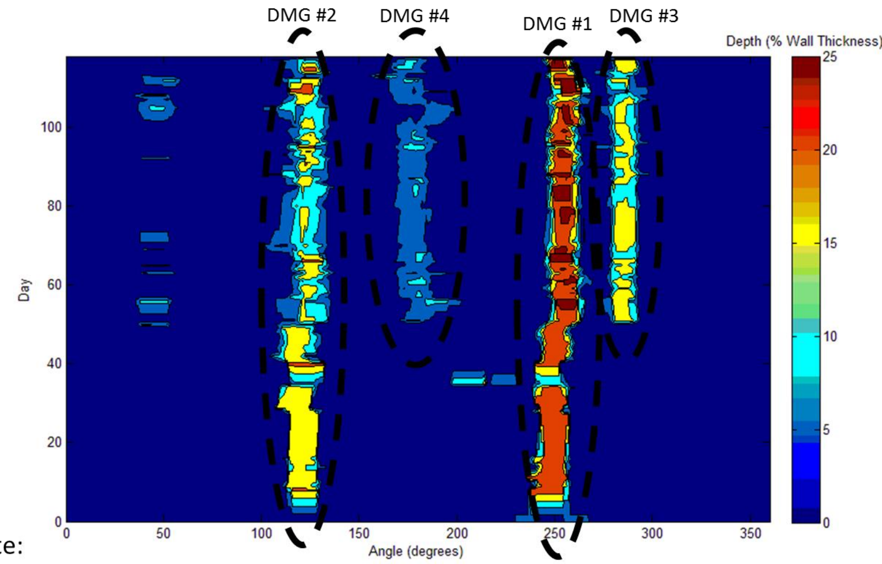
Source: Acellent RAPID Software Manual

7.5 Analysis of Damage Reports

Individual damage reports provide a snapshot of the damage detected on the pipeline at a given time. While this information is useful, it supplies only a static view of the pipeline state. A key advantage of the RAPID pipeline monitoring system is its ability to continuously monitor the pipe for damage. By aggregating the data together, it is possible to provide a more comprehensive and accurate view of the damage on the pipe as well as to monitor how it has changed and grown through time, and to detect the emergence of new damage areas as they occur.

To extract information on how the pipe being monitored had changed over time the individual damage reports generated by the damage detection portion of the software were loaded by the RAPID aggregation software. This software then proceeded to order the damage results chronologically utilizing the time stamps denoting when the data that had been used to generate the reports had been collected. The chronologically ordered data could then be used to generate a damage maps showing the different locations, sizes, and depths of damage detected. An example of the damage map generated from the system monitoring the pipe can be seen in the color plot in Figure 19. In the plot the x-axis was used to denote the angular location of the damage around the circumference of the pipe, the y-axis to denote the number of days since the system had begun operation and the color intensity to indicate the amount of wall thickness lost at that position up to that point in time.

Figure 19: Damage Map Generated from Blind Test with PG&E



Note:

- X-axis is the circumferential location along the pipe
- Y-axis is the time recorded in number of days since 6/4/2014
- Color intensity denotes a rough measure of wall thickness

Source: Acellent In-field Test Report

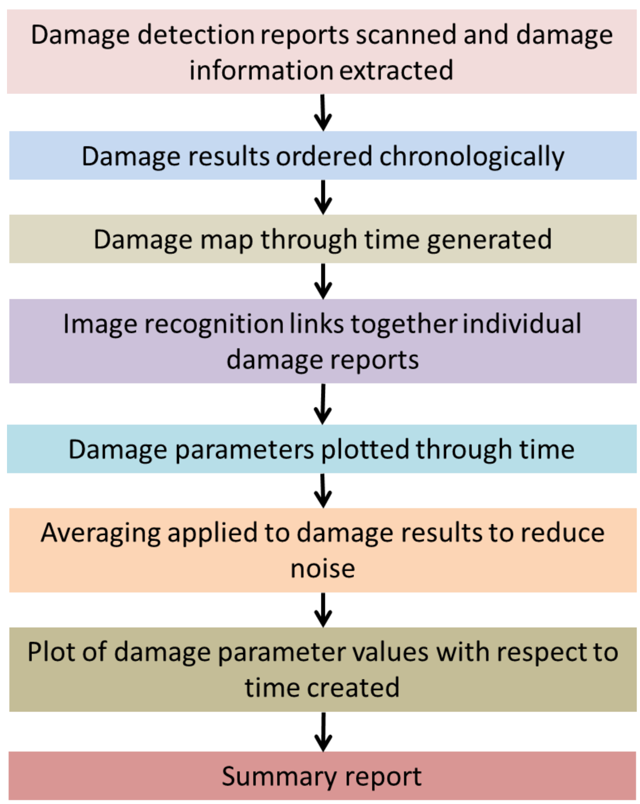
Using image recognition on the damage map the individual damage detection reports were linked together to show that there were four individual damage areas on the monitored pipeline. Two of these damage areas (denoted as DMG #1 and DMG #2) were installed during the early field testing and live demonstration of the system, the remaining damage areas (DMG #3 and DMG #4) were found to have been installed by PG&E personnel during the blind stage of the test. With the individual damage cases now identified the parameters for each damages could be separated and the results aggregated together to provide a plot of how the damage location and size had changed through time.

Once the individual parameters were plotted, a summary of all of the damage cases with their estimated location size and depth as well as any notes on changes in the damage was created. This result was shared with PG&E personnel who confirmed the accuracy of the results. This results summary can be seen in Table 6, while a flowchart describing the analysis process for aggregating the damage reports can be seen in Figure 20. The reference of detail test data analysis and damage detection plots is in Appendix A.

Table 6: Summary of Damage Estimates from RAPID System

	X (in)	Theta (Deg)	Diameter (in)	Depth (%)	Date Created
Case 1a	5.5	247.8	1.17	13.21	6/3/2014
Case 1b	5.9	254.0	1.5	25.35	6/6/2014
Case 2	6.6	121.6	1.5	19.12	6/6/2014
Case 3	6.3	286.0	1.4	16.97	7/24/2014
Case 4	5.5	178.4	1.6	11.43	7/24/2014

Figure 20: Flowchart of Analysis Process for Tracking Damage through Time



Source: Acellent RAPID Design Document

7.6 Test Summary

RAPID system development was completed in March of 2014. The system was then deployed to the Pacific Gas and Electricity (PG&E) for a period of more than 14 months. During this time period, a second monitoring station was also deployed on a bend section of pipe at ATS. With the assistance of PG&E personnel, new damage was introduced to the pipe surface in blind tests. The Acellent team was able to detect the damage and verified the sensitivity.

The results of those blind tests verified the damage detection capability of 1 percent of wall thickness loss sensitivity, and that the RAPID system was able to detect and provide a warning at 5 percent loss of total wall thickness. This demonstration has convinced PG&E that the system can provide multiple types of damage detection at multiple stations in gas pipelines.

7.7 Recommendations

After the validation of the system on the straight pipes and bend section at ATS, PG&E was interested in testing the configuration of pipeline with coating materials. Acellent has accepted the recommendation from PG&E and started to test the coated pipeline during the spring of 2015.

Another interest from PG&E was to verify the system performance for buried pipes. However, due to the budget and statement of work constraints of this program, the project team will need to find a new funding source and start the planning for performing this study in the summer, 2015.

CHAPTER 8:
Critical Project Review

The Critical Project Review meeting was held at the California Energy Commission office in Sacramento, on January 28, 2015. The attendants from Acellent Technologies were: Cas Cheung, Howard Chung, and Jeff Bergman; and from Energy Commission were: Dr. Avtar Bining, Fernando Pina, Alan Solomon, and Jamie Patterson.

8.1 Meeting Agenda and Minutes

The agenda was to review the program and its progress, and to get the approval for continuation of funding. The agenda is listed below:

- Goals of the agreement
- Objectives of the agreement
- Vision of the developed system and mission statement
- Progress and accomplishments for each tasks
- Project execution and budget review
- Conclusion of meeting
- Questions and answers

A detail meeting discussion and presentation material is in Appendix B. As a summary of the project progress at the time, Acellent completed the coordination with Pacific Gas and Electric company to deploy a monitoring system on an above ground regulator station for corrosion monitoring. The system design and development programs were completed. The testing and specification verification were done in the laboratory environment. The major accomplishments of the project were summarized as follows:

- In situ pipeline corrosion monitoring system was developed.
- The system was installed at the PG&E test facility. It has the capability of complete remote monitoring, in a 24/7 manner.
- The system has completed the blind tests with PG&E. The system can accurately and consistently detect the multiple corrosion damages.
- The system showed accuracy in the damage detection size and location at varied operation environment.

8.2 Results and Recommendations

Based on the conclusion of the meeting, the attendees agreed that the program has been running smoothly and the results of development and validations were satisfied. There are some recommendations from the PG&E for testing pipelines in the coating conditions. The company is willing to support the test on coated pipes with PG&E.

CHAPTER 9: Technology Transfer and Product Readiness Plan

9.1 Industry Analysis

9.1.1 Targeted Market

The targeted market for the proposed Real-time Active Pipeline Integrity Detection (RAPID) system is the oil and natural gas distribution industry. In the United States alone, there are over 2.2 million miles of oil/gas pipelines that need to be monitored for any damage. For the proposed system, the primary market focus will be for natural gas pipelines. Natural gas provides 27 percent of the marketable energy consumed in the United States. Natural gas is transported in high-pressure pipelines from producing areas to local distribution companies, storage areas, industrial end users, and electricity generation facilities. Key market needs within the United States of America and California, as well as globally, are explained below.

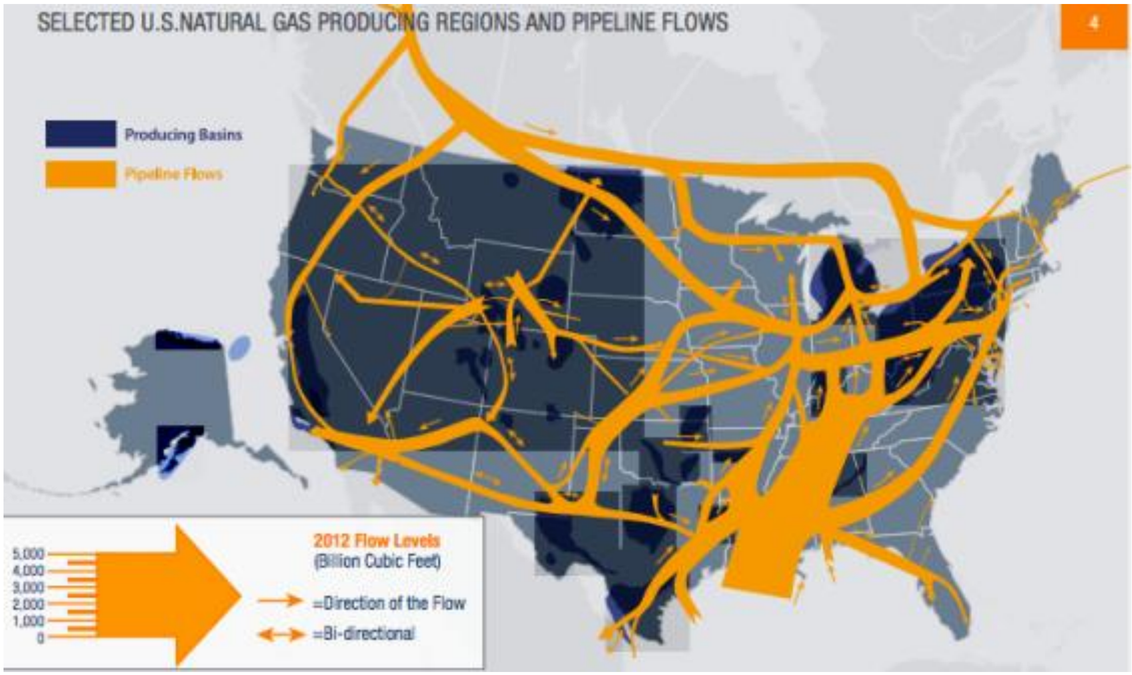
9.1.2 United States and California Market Needs

As can be seen in Figure 21, the natural gas pipeline network in the United States is a massive transmission and distribution system that is comprised of more than 210 pipeline systems spanning 305,000 miles that can deliver virtually anywhere in the Continental United States. These pipelines have more than 11,000 delivery points, 5,000 receipt points, and 1,400 interconnection points that transfer natural gas throughout the country, as well as 24 hubs that offer additional interconnections. There is a network of 1,400 compressor stations that maintain the pressure in the lines to ensure a constant flow.

In order to import liquid natural gas (LNG) domestically via pipeline from Canada, as well as export natural gas to Mexico, there are 49 locations where natural gas can be imported or exported within the United States. Additionally, there are 8 LNG import facilities and 100 LNG peaking facilities as well as 400 underground natural gas storage facilities. Additionally, there are 11 unique transportation routes within the US. Those include five transmission lines originating in the producing areas of the Southwest United States, two pipelines that extend from the Rocky Mountain region, and four routes that enter the country from Canada.

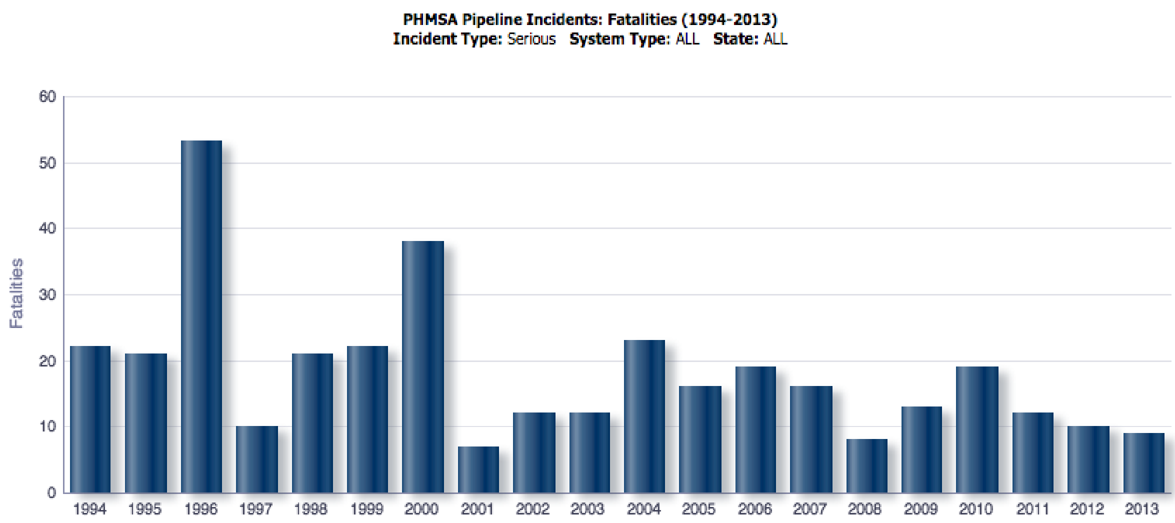
Safety is and always will be the natural gas industry’s first priority. Natural gas utilities spend more than $19 billion annually to help enhance the safety of natural gas delivery systems, however, as can be seen in Figure 22, a number of pipeline accidents occur every year.

Figure 21: Flow Level Chart of Natural Gas Production in USA



Source: www.api.org Natural Gas Producing Regions and Pipeline Flows

Figure 22: Natural Gas Pipeline Accidents (spills and explosions) in CA



Source: US Department of Transportation (US-DOT), Pipeline and Hazardous Materials Safety Administration (PHMSA)

For example, in September 2010, a natural gas pipeline explosion rocked neighborhoods of San Bruno, California, killing eight people. The National Transportation Safety Board investigated the cause, and in the words of Chairman Deborah Hersman, found “troubling revelations … about a company that exploited weaknesses in a lax system of oversight and government agencies that placed a blind trust in operators to the detriment of public safety.” A key reason for the apparent lack of pipeline oversight, according to the federal Pipeline and Hazardous Material Safety Administration (PHMSA), is the difficulty of maintaining a staff of inspectors, in part because of high turnover. Evidently, safety inspectors are highly sought after by pipeline companies, making it tempting for public inspectors to join the private sector and cash in on their experience.

Table 7 shows the number of pipeline incidents in California from 1994-2013 from the document of PHMSA pipeline incidents with an estimate of the cost associated with the incident.

Table 7: California State Pipeline Incidents Report 1994-2013

PHMSA Pipeline Incidents: (1994-2013)
Incident Type: All Reported **System Type:** ALL **State:** CALIFORNIA

Calendar Year	Number	Fatalities	Injuries	Property Damage As Reported
1994	54	0	9	$56,648,000
1995	31	3	4	$16,700,200
1996	24	0	5	$5,935,000
1997	28	1	2	$7,326,600
1998	29	0	6	$10,746,227
1999	20	1	4	$2,103,500
2000	23	0	2	$4,842,344
2001	14	0	1	$3,427,964
2002	48	1	1	$4,239,329
2003	49	2	4	$9,818,972
2004	48	5	3	$25,218,397
2005	49	0	1	$29,683,868
2006	57	0	3	$13,159,460
2007	55	0	5	$6,607,545
2008	59	1	6	$5,843,509
2009	48	0	0	$5,909,251
2010	36	10	56	$384,364,053
2011	36	0	0	$12,925,484
2012	43	3	1	$7,622,071
2013	37	0	0	$13,372,786
Grand Total	**788**	**27**	**113**	**$626,494,560**

Source: USDOT-PHMSA

9.2 Global Market Needs

Global expenditure for pipeline construction is expected to reach $216 billion over the next five years, increasing by 12 percent compared to the previous five-year period with over 270 thousand kilometers of pipelines expected to be installed. Major investment will be in pipe construction services (47 percent) and line pipe (27 percent). Increasing gasification is shaping the long-term demand profile for pipes. With an anticipated 35 percent increase in global energy demand over the next twenty years, the role of natural gas is expected to account for 26 percent of total energy consumption by 2030. This growing demand is also driving an increase in larger diameter pipelines.

Investment in new infrastructure to support LNG and unconventional gas developments will be a major factor shaping future demand for pipelines. Outside the major oil province of the Middle East, gas-related lines accounted for 67 percent of km installed over the past five years with this figure expected to increase over the 2013-2017 period.

9.3 Market Trends

The primary materials used to construct natural gas pipelines are steel and plastic and are susceptible to premature aging and degradation. One of the leading causes of metallic pipeline failures is corrosion, whereas nonmetallic or composite pipelines are prone to cracking. These damaged pipelines can be inspected using a variety of nondestructive methods; however, when a damaged area is located, the pipe must be exposed and inspected to determine if the extent of the damage requires repair or replacement. There is no reliable, built-in nondestructive method for determining if the damage is enough to affect operational safety. Existing methods require the pipeline to be shut down, resulting in revenue losses for the utility and potential outages for customers.

The proposed RAPID System offers the potential to provide a complete solution for a wide range of structural inspection, analysis, evaluation, and maintenance requirements and enable a number of high value economic benefits to the oil and gas pipeline industries.

The oil and gas transmission and distribution industry has needed such a tool for decades. The chances of pipeline damage will inevitably increase as the nation's oil and gas industry installs more transmission and distribution pipelines to meet the nation's growing demand. For example, demand for natural gas in the United States is projected to expand faster than any other fuel source during the next two decades, largely because more power companies are using natural gas to generate electricity. According to the Energy Information Administration, the amount of electricity generated from natural gas could triple between 1999 and 2020. The National Petroleum Council, an advisory committee to the Secretary of Energy, recently forecasted the need for more than 38,000 miles of new gas transmission lines and 263,000 miles of distribution mains by 2015.

9.4 Market Share and Implementation

The Structural Health Market has been rapidly growing over the past decade. The overall SHM market can be estimated as follows:

Table 8: Overall Markets

Traditional SHM Market Commercial Aircraft, Military Aircraft & Rotorcraft, Pipelines, Bridges and Wind, Solar & Machinery	**Emerging SHM Market** Data Analytics, New Composites for Automotive, Vehicle Armor, Space & Satellite Systems, Data Centers, Dry Docks & Cargo Shipping and Intelligent Transportation Systems
2014 - $38.6 Billion	**2014 - $5.9 Billion**
2020 - $56.4 Billion	**2020 - $64.5 Billion**

Source: Acellent internal documents

In order to target the pipeline market and implement the RAPID system, Acellent plans to work with utilities such as PG&E and SoCal Gas, pipeline owners such as Chevron, and chosen inspection teams who normally do the inspection process for the pipeline owners such as Applus. This collaboration will lead to defining the requirements for implementation and training for a pipeline SHM system. From information gathered from the pipeline partners, Acellent will initially target "high-risk" areas that incur a very large amount of cost NDI (nondestructive inspection) due to structural integrity issues. In the long-term, the lower risk areas that are typically difficult to inspect using conventional nondestructive inspection (NDI) techniques would also be addressed.

9.5 Marketing Strategy

Since nearly all in-service structures require some form of inspection for monitoring their integrity and health condition to prolong life span or to prevent structural integrity deterioration, the potential applications are very broad. Acellent has worked with a number of industries and companies, spanning the spectrum from aerospace to civil infrastructure, to help solve their structural inspection issues. For example, Acellent is working with key aircraft manufacturers such as Airbus and Boeing to utilize the SHM systems for monitoring of their new aircraft including the Airbus A350 and Boeing 787.

The focus of the company in the coming five years of operation will be to develop commercial products with targeted partners and to disseminate applications potential of the SHM systems at structural health monitoring conferences, seminars, and symposia, and to ensure that the SHM systems are manufactured to the highest possible QC/QA standards.

A Five-Year Marketing Plan has been developed to achieve commercial success for the company's products. Marketing focus and expectations incorporated into this Five-Year Plan are presented below:

Figure 23: Five-Year Plan

Year 1	Year 2	Year 3	Year 4	Year 5+
Creating alliances and consortiums to firm up support in various market sectors targeted in the near-term, expanding worldwide distribution network for product sales	Increasing marketing force to promote products in the targeted markets and promoting benchmark or trial studies with industries	Scaling-up the marketing group to focus on sales and marketing	Expanding alliances and consortium to penetrate bigger markets	Increasing marketing efforts to procure commercial scale sales of products in all targeted industrial sectors

Source: Acellent internal documents

9.6 Anticipated Production Plan

9.6.1 Migration from R&D to Production

The creation of Acellent Technologies Inc. stems from the work conducted by members of the Aeronautics and Astronautics Department at Stanford University. Faculty member Dr. Fu Kuo Chang and his students developed novel methods to manufacture the SMART Layer - a network of sensors embedded in a thin film and diagnostic methods thereof. Acellent Technologies Inc. licensed the SMART Layer patent and was formed to commercialize the research in 1999.

Through targeted growth over the years in manufacturing and production of advanced sensor and monitoring technologies, the company has become an industry leader in the area of "Structural Health Monitoring (SHM)".

Acellent currently has:

- World-class researchers who are knowledgeable about SHM technologies and their market need access to state-of-the-art manufacturing, modeling, design, engineering, analysis, and drafting capabilities in the proximity of California Silicon Valley region, Bay Area.
- Quality control and assurance programs for every product, certified by AS9100 and ISO9001.
- Experienced and knowledgeable management team with a thorough understanding of the technologies and the target markets.
- Exemplary Board of Directors to guide the company direction.

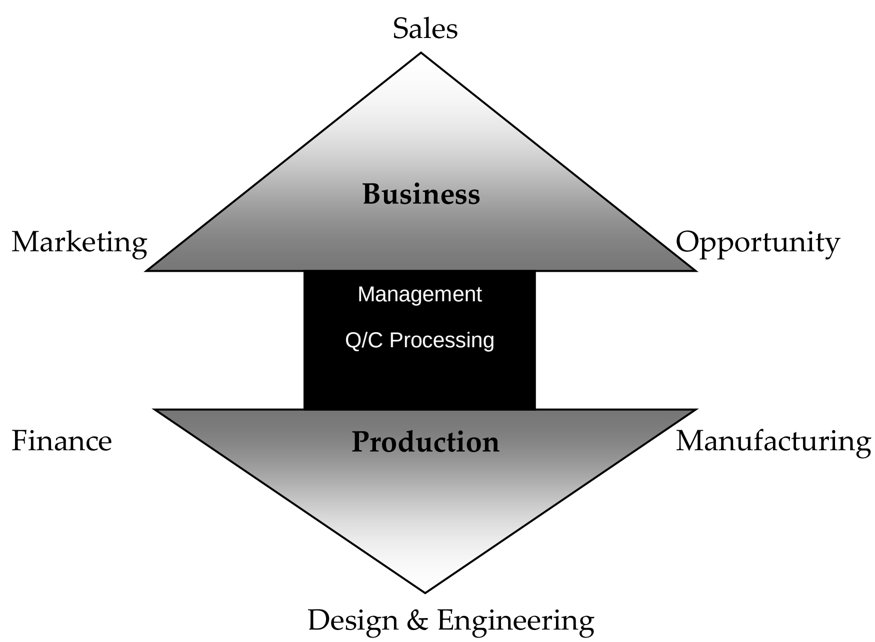
On the roadmap towards the mass production of its SHM technologies, the company has identified the needs for a planned migration from R&D Engineering to large-scale production. To this end, the company needs to:

- Clearly identify the market shares of SHM technologies applied in the natural gas pipeline industry and the projection of return rate from the capital investment required for the setup for large-scale production.
- Identify the geographic location for production, in terms of supplying materials, transportation of products to clients, and cost of setting up the facilities and labor for execution of production.
- Identify contingency plans for growth of the company from different investment sources and develop a production revenue roadmap.

9.6.2 Production Barriers

Although Acellent believes that, its breakthrough technologies and products are well received and will constitute a substantial marketing success, possible technology/market risks exist that can limit the success. Figure 24 illustrates the flow from engineering and design to production. In order to go from production to delivery, our products need to pass through a very stringent quality control gate to obtain management approval for release to sales. The supporting factors of making sales are marketing and the opportunities encountered in the business sector. The supporting factors for enabling large-scale production of our products are the finance and manufacturing capabilities.

Figure 24: Design Engineering Towards Sales of Product



Source: Acellent Internal Document

Acellent has identified the following barriers that are considered crucial for improvements required by the production plan:

Renewal of Manufacturing Equipment: efficiency for volume production needs suitable equipment and facility setup.

The equipment for our current production facility was setup during the years of 2004-2005. The equipment and facilities are outdated and cannot be used for high volume production. Some capital investment is crucially required for the purchase of new equipment and improvements to our current production facilities.

Fully automated or semi-automated manufacturing process: several steps in our current manufacturing processes are labor intensive and require a large amount of supervision to achieve consistent high quality products.

Introduction of automation for some of those processes will greatly improve the production rates and provide better management of production quality and efficiency.

Quality control: High quality products need to be used in SHM systems to meet our customer requirements.

Acellent Technologies Inc. is certified in SAE AS9100:2009 Rev. C standard for quality management systems in the aerospace industry, covering requirements for quality and safety relevant to aerospace, and is widely accepted by aircraft and aerospace manufacturers and suppliers as a benchmark. The company is also certified in ISO 9001:2008 quality management standard. These two certifications ensure the highest quality of materials used in Acellent's products. Care must be taken to ensure that the same quality standards are met as our production rates are increased.

Installation and usage: The SHM products require standardized installation procedures, kits or tools, and pre-operation calibration processes.

Acellent believes that its SHM products are simple and easy to install and use with all types of materials and structures. The SMART Layer sensors are encased in a thin-dielectric film that can easily be integrated with any structure. Acellent's diagnostic hardware has already been installed and integrated on several platforms. Acellent has developed standard methods for installation and usage of its products.

Mitigation of Other Technology/Market Risks: The nature of high technology small business operation is that they face enormous potential as well as numerous anticipated and unanticipated risks.

The hallmark of a successful high tech small business is its ability to adapt to new challenges and to alter its business plan and redirect its energy and assets as the market may dictate. Acellent believes that it is capable of successfully reacting to unanticipated risks and can successfully manage such risks as they arise in order to keep the company on a successful growth path.

9.6.3 Investment Threshold

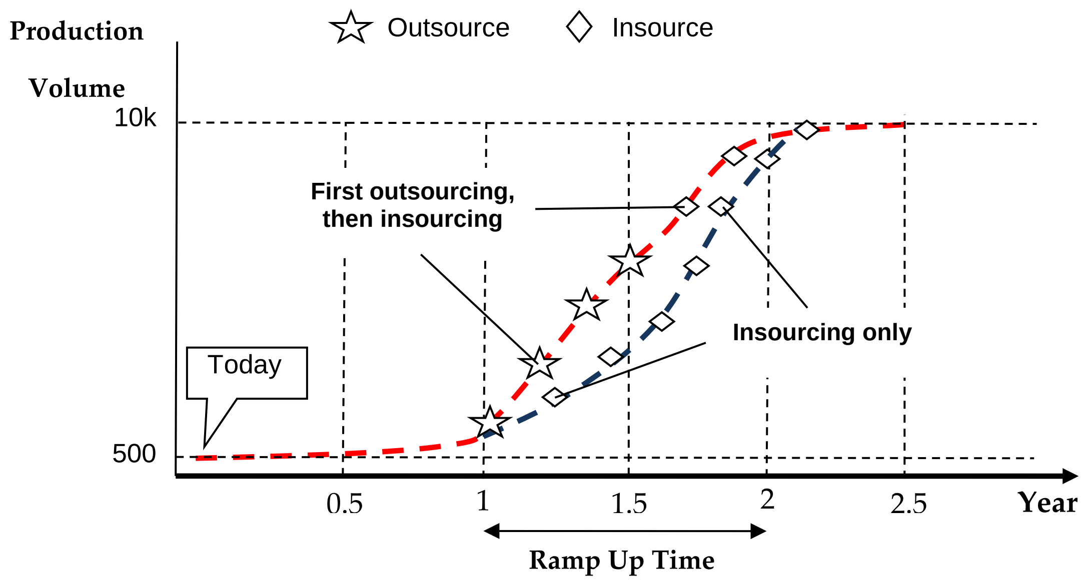
The threshold for making effective investments to improve our current facility to a volume production facility is to renew the manufacturing equipment and make automated or semi-automated manufacturing processes in the areas requiring heavy labor interruption. The company has identified the crucial facts about the needs for becoming a warehouse of manufacturing.

Acellent currently utilizes funds received from worldwide sales for its marketing, and research and development efforts. In the near future, Acellent plans to obtain external funds from third-party investors to fund its marketing and growth needs. The funds received will enable the use of high rate manufacturing methods for the RAPID system sensor networks and diagnostic hardware resulting in substantial reductions in price, and accelerated marketing of the RAPID system to the natural gas pipeline market worldwide.

9.6.4 Plan to Ramp Up to Full Production

Acellent has set up a plan to ramp up production from the current annual 500 units to 10,000 units, in 2 to 3 years. However, additional resources, people, equipment, and training (skill) of the people will be required to achieve this goal. It is anticipated that the resources can be obtained with the sufficient installment of capital funds from investments either internally or externally. The risk of investing internally is usually higher than utilizing various outsourcing solutions. Therefore, the five-year production plan includes more than one approach in the ramp up period. Figure 25 illustrates the possible approaches for the production growth plan. The first example (red curve) applies outsourcing as a transition for production, then, implements the insourcing facility. In this manner, the use of strategies that utilize partially outsourcing and insourcing solutions can avoid the risk of requiring big capital investment. Unlike the first approach, the company can go with the insourcing only (black curve) approach for the full initial investment for complete insourcing of manufacturing. Potentially, the full insourcing approach could decelerate production volume due to a shortage of personnel or readiness of equipment, and can be more risky during the length of the investment return period.

Figure 25: Production Growth Plan



Source: Acellent internal documents

9.7 Summary of Technology Transfer and Future Growth

9.7.1 Technology Transfer in California

The RAPID system can be applied to any natural gas pipeline worldwide. Within the State of California, Acellent plans to work with utilities such as Pacific Gas and Electric (PG&E) and Southern California Gas (SoCal Gas). PG&E has tested the system during the course of this program. Together these utilities have over 8,000 km (5,000 mi) of natural gas transmission and distribution pipelines. While optimally the RAPID system would be deployed over the entire length of pipeline in California, conservatively the system may only be applied to one-eighth (12.5 percent) of the total mileage primarily in high-risk areas. Based on this assumption, the total savings of deploying the RAPID system can be conservatively estimated to be about $3.5 billion to the California ratepayers. The hardware of the RAPID system is relatively inexpensive costing under $100,000 per mile. While the total installed cost is more difficult to quantify at this stage it can be expected not to exceed $1 million per kilometer (equipment plus installation). As a result, over the estimated deployment area (1000 km) the estimated net savings due to the RAPID system can be expected to exceed $2.5 billion over the 25-year lifetime of the system. It should be noted that while the estimated savings are approximate, it does not include any savings due to the use of the RAPID system deployed in other critical areas for damage and degradation monitoring.

9.7.2 Strategic Collaborations for Future Growth

Acellent is in excellent position for significant future growth. The company has

- Clear messages from customers needing rapid & scaled up implementations.

- Recognition of Acellent technology leadership in SHM continually increasing.
- Potential partners exploring strategic collaborations.
- Industry infrastructure for *Internet of Things (IOT)* exploding and ready for adoption.

The company has established engagements with key potential partners and customers:

- Verizon for data communication
- Intel for gateway alignment & solutions *(Selected by Intel as preferred development partner)*
- PG&E and other pipeline companies for domain applications

CHAPTER 10: Summary and Recommendation

10.1 Summary

In this two-year research and development program, the prototype Real-time Active Pipeline Integrity Detection (RAPID) system was designed, fabricated, and tested. The system performance was validated through extensive testing from initial laboratory tests at the component level to field tests performed at the utility facilities. The complete system was validated on a selected gas pipeline at the Pacific Gas and Electric (PG&E), Advanced Technology Service (ATS) center, in San Ramon, California. During a 14-month test period, different sizes of corrosion-simulated damages in different depth configurations were introduced to the test pipeline section that was being monitored by the RAPID system. The RAPID system detected the damage locations and quantified the sizes of those damages quickly. The results were verified with the pipeline owner and confirmed with a third party nondestructive inspection tool, such as a laser scanner. With mobile wireless communication, the data and real-time information was then transmitted to a remote monitoring site.

In addition to the successful achievement of the technical objectives of the program, Acellent's business department investigated potential marketing strategies and laid out a potential production growth plan for the large-scale manufacturing of the RAPID system. The company is setting a one-to-two year program for mass production of the RAPID system once the final capital investment is in place. It was shown that the system could be fully produced and supplied to the pipeline industry for monitoring the safety of natural gas pipeline assets and providing alerts to the end users of the occurrence of any potential damage to the facilities caused by natural or man-made events.

10.2 Recommendation

The company will continue to work with utilities, such as PG&E, SoCal Gas, and SDG&E for additional technology demonstration and technology transfer opportunities. The recommendations from the current investigator at PG&E were very beneficial to the company. More efforts should be placed on improvements to the system and adjustments for in-field deployment applications. It is recommended that additional field testing of the RAPID system be conducted to demonstrate the system reliability in actual field environments and to develop plans for field implementation and deployment.

Currently, the request by PG&E to verify the RAPID system performance for underground applications is being considered. In collaboration with PG&E, Acellent would like to investigate the applicability and demonstrate the feasibility that the system can be used for field deployment to underground conditioned pipelines.

GLOSSARY

Term	Definition
2D/3D	Two dimensional or three dimensional matter
CEC	California Energy Commission, usually called Energy Commission
CPM	Commission Program Manager
dB	Decibel ratio, an unit of quantifying the amplification of signal amplitude
DMG	Notation for damage
GUI	Graphical User Interface, the window skin of the software
HLA	High Level Architecture
Hz, kHz, MHz	Unit for quantifying the frequency of signals
NEMA	National Electric Manufacturing Association, for setting the standard for instrument and enclosing design of electric component
PG&E	Pacific Gas and Electricity
PZT	Lead, Zirconium, Titanate compound. It is an intermetallic inorganic compound with the chemical formula that can perform like piezoelectric material.
QA/QC	Quality assurance and quality control, a process to ensure the product delivery quality to meet requirements
RAPID	Real-time active pipeline integrity detection
SHM	Structural health monitoring
VGC	Electric component for vector generation controller

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Li, Franklin, et al. 2011. "RAPID System for Hot Spot Corrosion Monitoring of Gas Pipelines." *Proceedings of the 8th International Workshop on Structural Health Monitoring*: 733-742. Stanford University.

Qing, Peter, et al. 2009. "Real Time Active Pipeline Integrity Detection System for Direct Assessment of Corrosion." *Proceedings of the 7th International Workshop on Structural Health Monitoring*: 365-374. Stanford University.

APPENDIX A:
Infield Test Data and Plot of Wall Thickness Loss

The resulting raw data plots showing all of estimated location, size, and depth estimates can be seen in Figures 26-29.

Figure 26: Raw Damage Detection Results for DMG #1

	X (in)	Theta (deg)	Diameter (in)	Depth (%)
Mean	5.91	253.99	1.48	25.35
Stdev	0.44	6.06	0.25	1.73

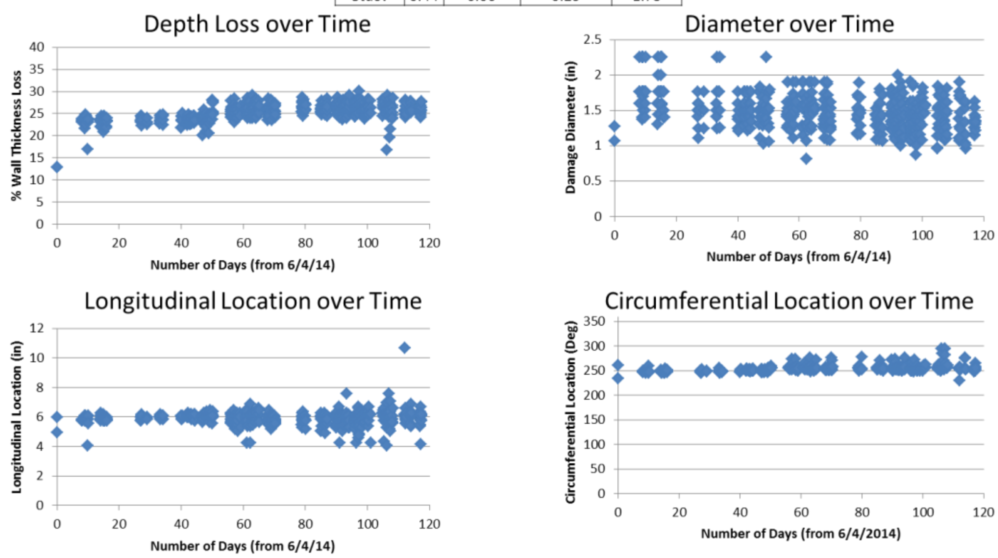


Figure 27: Raw Damage Detection Results for DMG #2

	X (in)	Theta (deg)	Diameter (in)	Depth (%)
Mean	6.60	121.61	1.54	19.12
Stdev	0.75	5.13	0.26	2.08

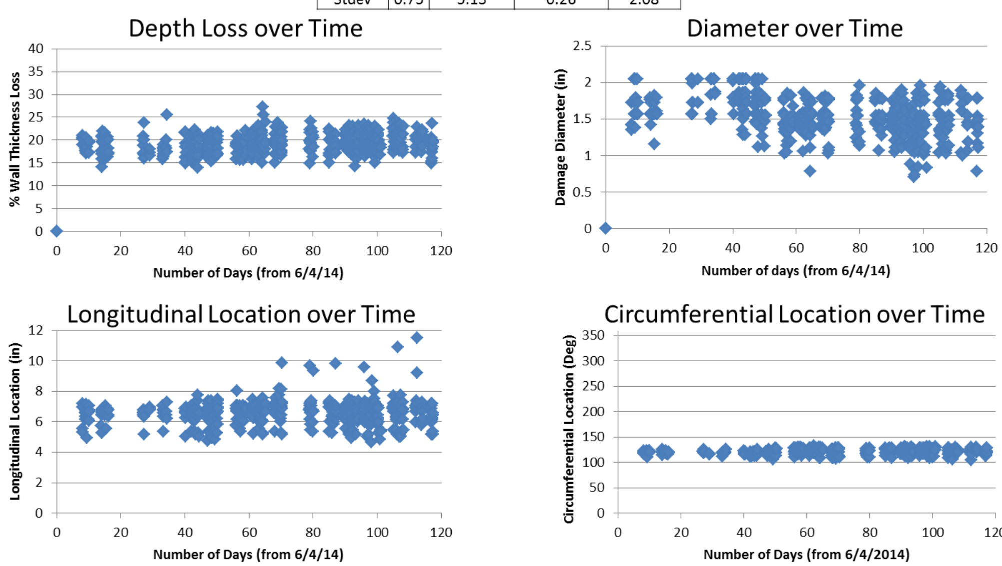


Figure 28: Raw Damage Detection Results for DMG #3

	X (in)	Theta (deg)	Diameter (in)	Depth (%)
Mean	6.29	285.95	1.37	16.97
Stdev	0.42	3.07	0.14	1.45

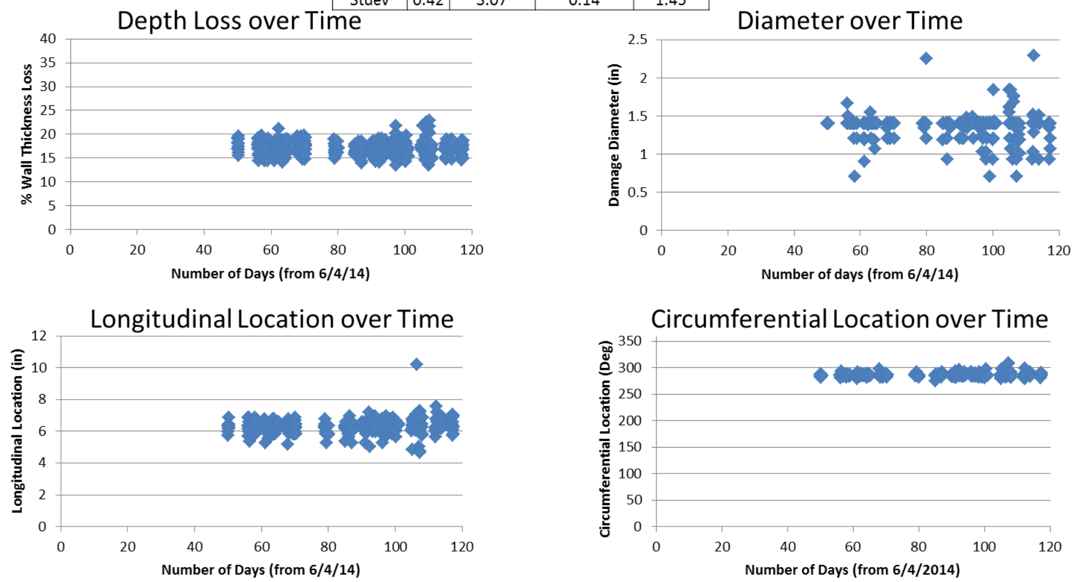
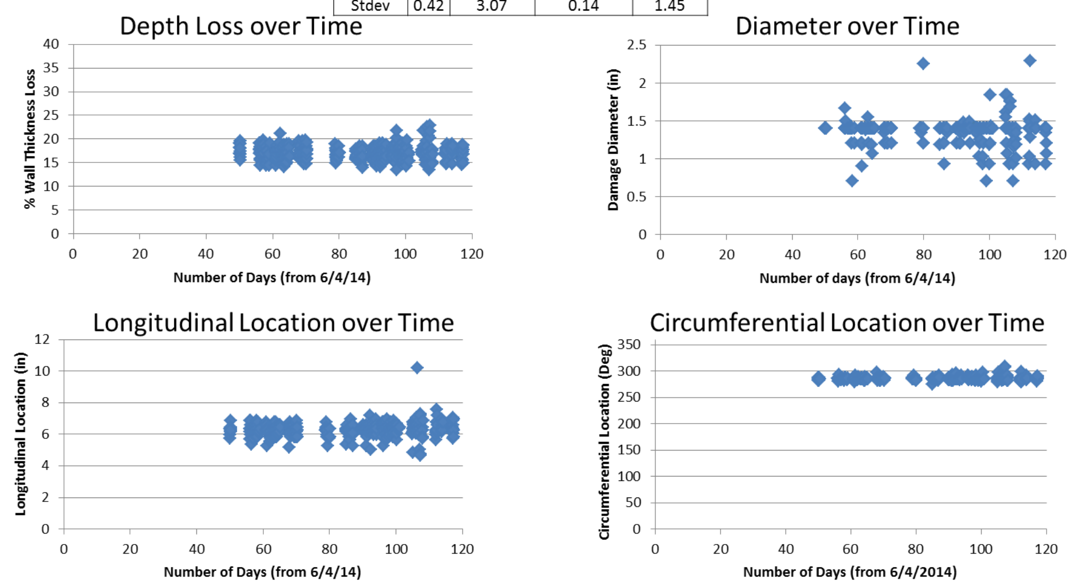


Figure 29: Raw Damage Detection Results for DMG #4

	X (in)	Theta (deg)	Diameter (in)	Depth (%)
Mean	6.29	285.95	1.37	16.97
Stdev	0.42	3.07	0.14	1.45



As can be seen from the raw data results there is some variation in the data from measurement to measurement. This variation is white noise introduced into the measurements by natural variations in environment and other external conditions that cannot be completely eliminated. As a result, in order to provide a more accurate view of the damage parameters, a simple five point moving average is applied to the data, which reduces the effect of white noise. After applying the moving average techniques, the resulting data was plotted out for the user. The resulting estimates of the change through time for each parameter of each damage case can be seen in Figures 30-33.

Figure 30: Running-mean Results of Damage Parameters for DMG #1

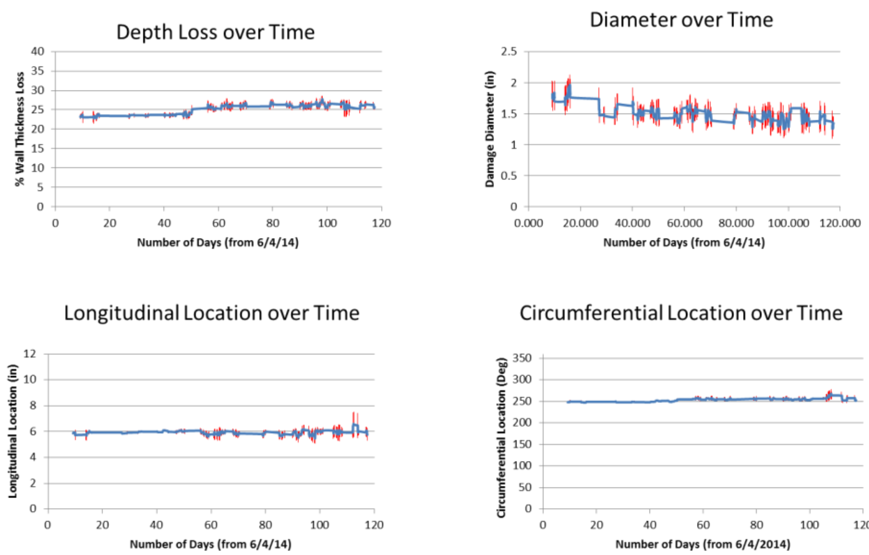


Figure 31: Running-mean Results of Damage Parameters for DMG #2

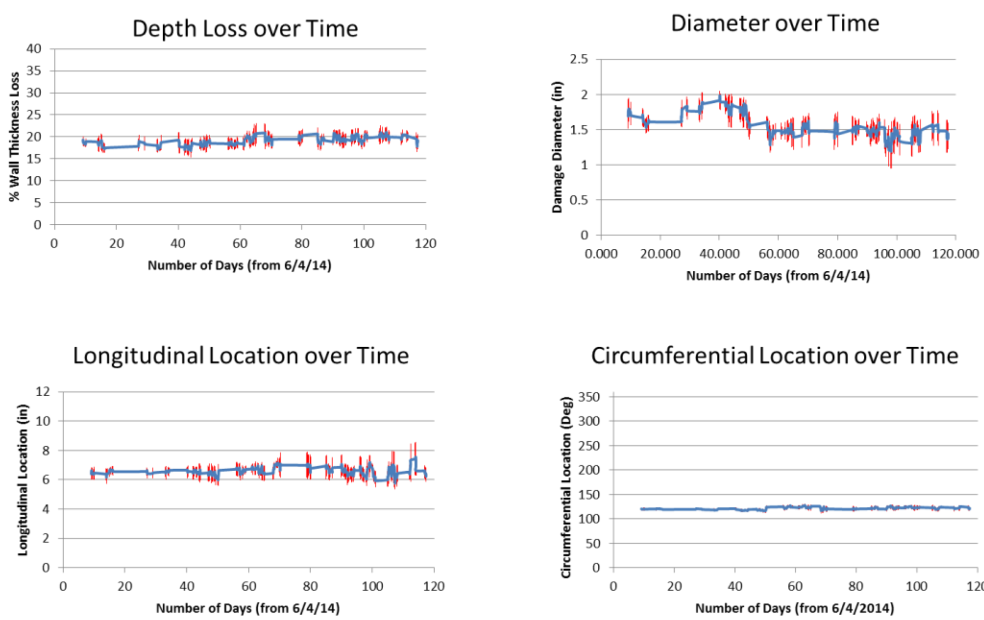


Figure 32: Running-mean Results of Damage Parameters for DMG #3

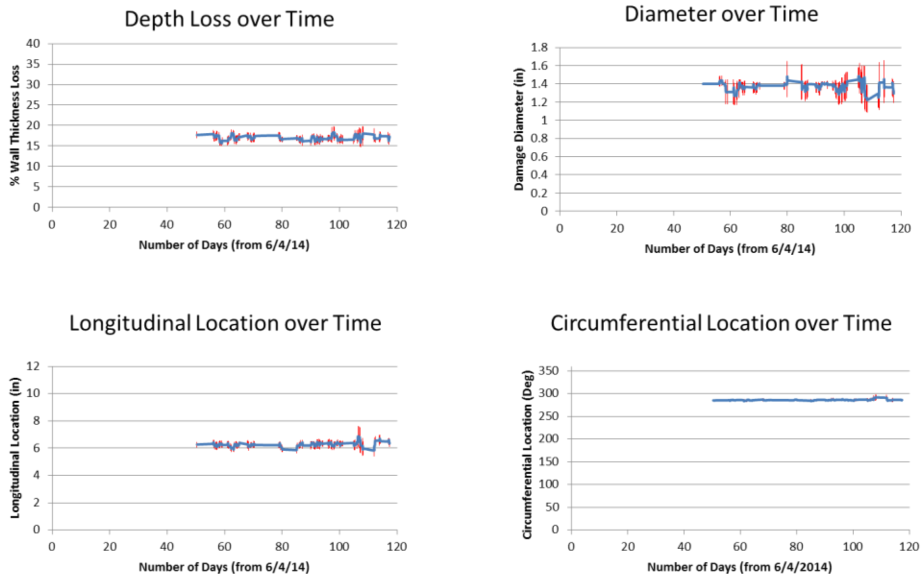
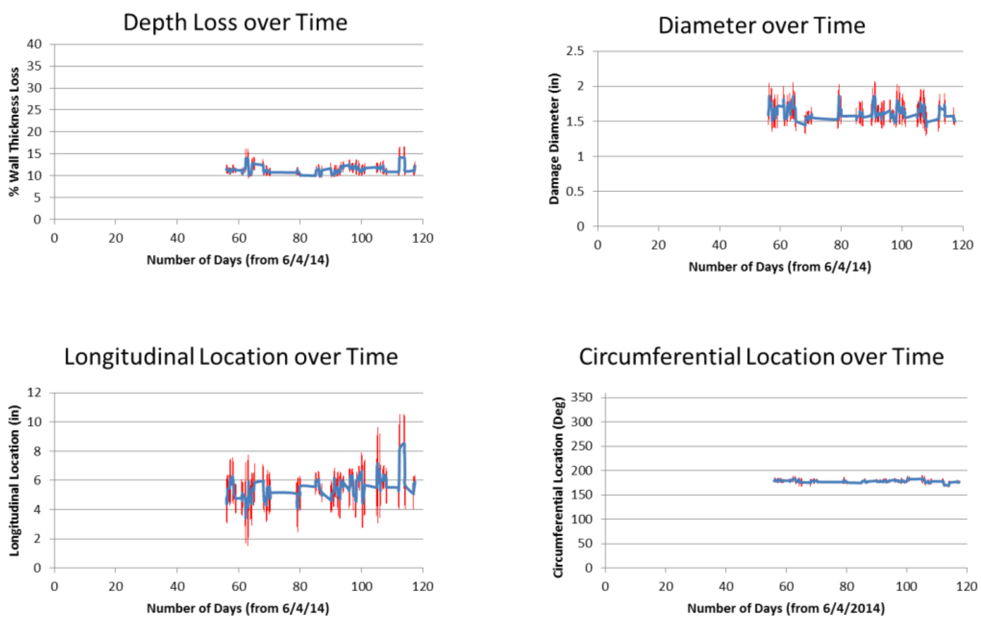


Figure 33: Running-mean Results of Damage Parameters for DMG #4



APPENDIX B:
Critical Project Review Slides

CALIFORNIA ENERGY COMMISSION

Agreement PIR-12-013
RAPID System for Pipeline Structural Health Monitoring

Critical Project Review Jan. 28, 2015

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Participants

Acellent:

Cas Cheung, Howard Chung, Jeff Bergman

California Energy Commission:

Avtar Bining, Fernando Pina, Alan Solomon, Jamie Patterson

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CALIFORNIA ENERGY COMMISSION

Outline

- Goals of the Agreement
- Objectives of the Agreement
- Vision of RAPID
- Mission Statement
- Progress and Accomplishment- Tasks
- Project Execution and Budgetary Review
- Concluding Remarks
- Questions and Answers

3

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Goals of the Agreement

- Maintain the safety of the pipeline system
- Accurately measure a crack in a pipeline while it is in the ditch, and transmit pipeline data to the back office.
- Reduce structural inspection costs, avoid unplanned pipeline failure, and move from schedule-driven to condition-based maintenance monitoring.

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Objectives of the Agreement

- Obtain real-time information on the integrity of a structure during service
- Identify visible and invisible damage in gas pipeline structures
- Assess damage information from structural anomalies including:
  - fatigue cracks in welded joints
  - Corrosion damage in the pipeline system
- Provide an easy to use inspection tool for maintenance personnel.

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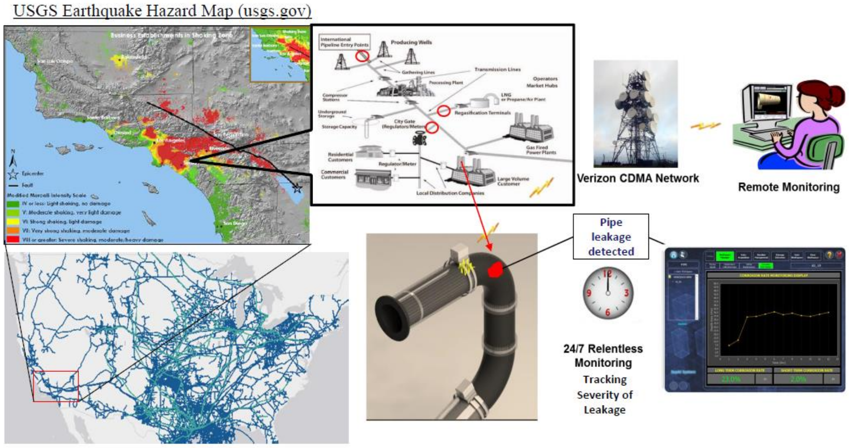
Vision of RAPID System for Gas Pipeline

USGS Earthquake Hazard Map (usgs.gov)



Natural gas pipeline network
www.greenovateboston.org

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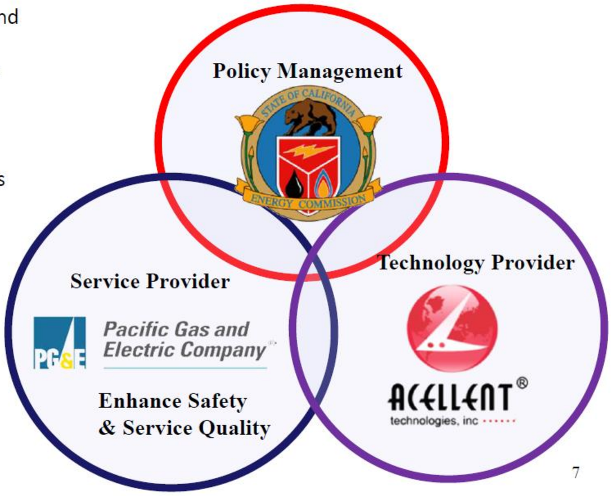
Government-Industries Partnership

- 6/24/2013 Acellent and PG&E Initial Technical Discussion on Product Requirements
- 7/15/2013 Project kickoff. Meeting with CEC PM Contact points and Finalize Tasks
- 2014-June RAPID System Deployed to PG&E ATS Test Site
- 2014-Dec. Finished Technology Development



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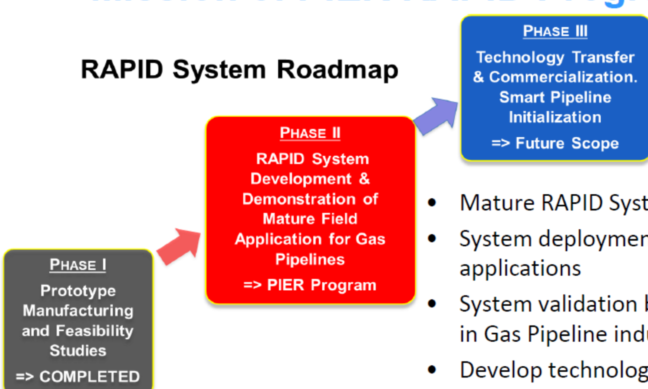
Mission of PIER RAPID Program

RAPID System Roadmap



- Mature RAPID System
- System deployment for field applications
- System validation by end user in Gas Pipeline industry
- Develop technology transfer plan

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Major Accomplishments

- Developed an in-situ pipeline corrosion monitoring system meeting PG&E specifications.
- Installed the system at PG&E test lab with complete remote monitoring capability and active 24X7ongoing testing.
- The system, in blind tests detected accurately and consistently multiple corrosion damages induced by PG&E.
- The system showed capability for corrosion damage detection accuracy for both location and size under varied environmental conditions.
- *In the future, the entire system can be miniaturized and mass produced for deployment in the gas industry in a cost effective manner.*

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Acellent Agreement PIR-12-013

Name of Initiative	Description	Status
Real-Time Active Pipeline Integrity Detection (RAPID)	Continuous pipeline monitoring using piezoelectric acoustic ultrasonic transducers/sensors. The system can provide long-term service to evaluate the corrosion rate, corrosion locations of pipelines and alert the utility companies when their pipelines are outliers from safety thresholds.	Coordinated with PG&E to deploy a monitoring system on an above ground regulator station for corrosion monitoring. Also, completed design and development of monitoring system using specifications from PG&E and laboratory testing. **Next steps:** 1. Full scale pipeline and multiple-station demonstration during Spring 2015 2. Final Report will be available during Summer 2015 3. Collaborate with PG&E and utility companies for technology transfer strategies and product commercialization.

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Progress and Achievement Review

TECHNICAL TASK LIST

Task #	Task Name
1	Administration
2	Establishment of Requirements for RAPID System Design
3	Sensor Design, Optimization, and Packaging
4	Hardware Development for Optimum Data Acquisiton
5	System Level Design and Integration
6	System Reliability Issues
7	Software Development
8	System Testing and Validation
9	Technology Transfer Activities
10	Production Readiness Plan

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Task 1: Administration- Product List

No	Products	Due Date
1	kick-off Meeting	7/16/13
2	Report, List of Requirements	9/2/13
3	Report, Sensor Optimal Design	10/30/13
4	Interim Report, Hardware Development	1/31/14
5	Final Report, System Reliability	3/3/14
6	Final Report, System Level Design	3/3/14
7	Interim Report, Software Development	4/2/14
8	Final Report, Software Development	6/3/14
9	CPR Report	6/3/14
10	Interim Report for System Validation in Coupon Level	10/1/14
11	Final Report for in-field Demonstration	1/30/15
12	Draft Data Analysis Report	1/30/15
13	Final Data Analysis Report	1/30/15
14	Draft Technology Plan	4/1/15
15	Final Technology Plan	6/2/15
16	Draft Readiness Plan	6/30/15
17	Final Readiness Plan	7/30/15
18	Monthly Progress Reports	30th each mo.
19	Final Outline of the Final Report	2/16/15
20	Draft Final Report	4/6/15
21	Final Report	6/29/15

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Task 2: Establish Requirements

System Requirement

Sensor

- Reliable bonding/adhesive
  - Temperature <300 °F
  - Survive >15Y in harsh environments
- Stable coating material
- Sensor density design
- POD > 95% for crack and corrosion detection
- Convenient and reliable sensor and system installation procedures
- Self diagnostics capability

Hardware

- Robust enclosure
- Hazardous requirement certification
- Robust design with sustainable computing and power supply for DAQ and diagnostics:
  - 32 Channels
  - Battery Life 5Y, Re-Chg
- Wireless available (Smart Meter)
- Connectivity robustness

Software

- **Local command line software for DAQ and FTP data transmission**
  - **Autonomous DAQ**
  - **Time registration for synchronization**
  - **Self system integrity check**
- **Remote data management storage and data interpretation**
  - **Smart Patch software for multiple zones/hot spots crack/corrosion detection algorithms**
  - **Debris removal algorithm**
  - **Damage mapping after analysis**
  - **3D tools for visualization**

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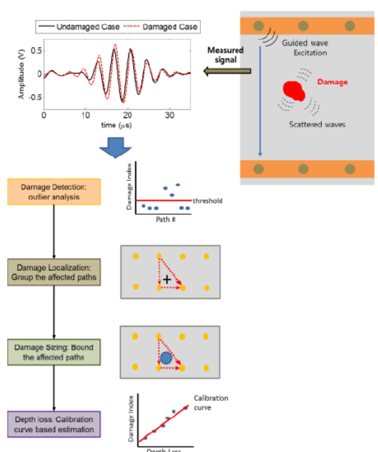
Task 3: Sensor Optimization & Design

- The RAPID system operates based on the guided Lamb-wave propagation network sensors
- Acoustic wave propagation analysis can be used to detect crack damage and corrosion
- Sensitivity of damage location and size were analyzed through material simulation and to laboratory test to come up an optimal sensor layout designs



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Task 3: Sensor Optimization & Design

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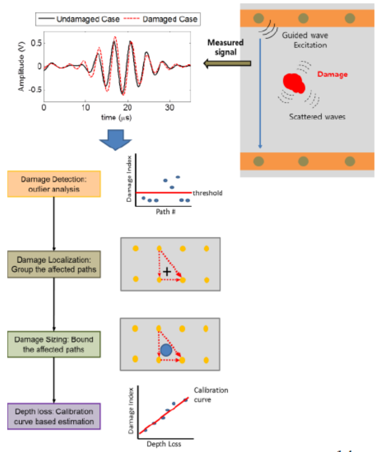

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Task 3: Sensor Optimization & Design(cont'd)

- The sensors are protected with the fiber glass resin composite wrap for harsh environment resistance
- Based on the material study, the protected sensor system can meet with ASME AARP A4.1 Requirement, and used for 20 years life cycle.

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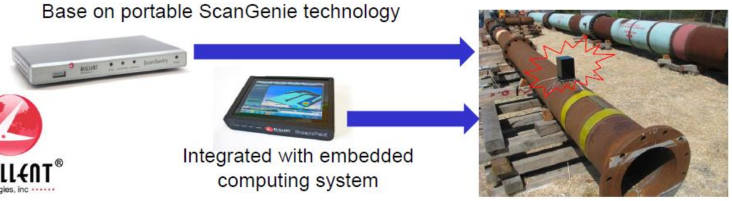
Task 4. Hardware Development

4	Hardware Development		9/2/2013	1/17/2014
		4.1	Hardware Architecture Design	9/2/2013	9/16/2013
		4.2	Specifications and components chart	9/16/2013	9/30/2013
		4.3	R&D Component part and prototyping	10/1/2013	10/30/2013
		4.4	Hardware validation and production	11/1/2013	12/13/2013
		4.5	Communications Hardware Design	9/2/2013	9/30/2013
		4.6	Power Board Design	9/9/2013	11/1/2013
		4.7	Hardware Package design	11/1/2013	12/1/2013
		4.8	Hardware testing and validation	10/1/2013	1/2/2014
		4.9	CPR report of hardware	1/2/2014	1/17/2014

Base on portable ScanGenie technology



Integrated with embedded computing system

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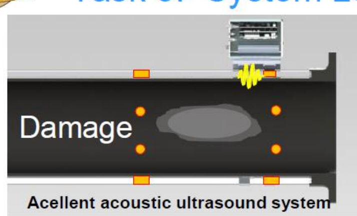
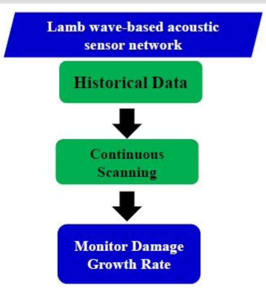
Task 5. System Level Design & Integration





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Task 5. System Level Design & Integration (cont'd)

System Specifications

Sensor

- Reliable bonding material /adhesive
  - Temperature <250 ºF
  - Survive >15Y in harsh environments
- Stable coating material
- Sensor density design
- POD > 95% for crack and corrosion detection
- Convenient and reliable sensor and system installation procedures
- Self diagnostics capability

Hardware

- Robust enclosure
- Hazardous requirement certification
- Robust design with sustainable computing and power supply for DAQ and diagnostics:
  - Act. voltage P-P95V
  - 32 Channels
  - Battery power to sustain 3~ 5 years of operation
- Wireless connectivity through partnership with Verizon communication systems
- Connectivity robustness

Software

- Local command line software for DAQ and FTP data transmission
  - Autonomous DAQ
  - Time registration for synchronization
  - Self system integrity detection
- Remote data management storage and data interpretation
  - RAPID software for multiple zones/hot spots crack/corrosion detection algorithms
  - Debris removal algorithm
  - Damage mapping after analysis
  - 3D tools for visualization

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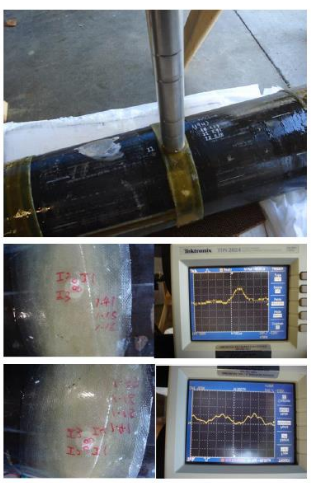
Task 6. System Reliability Test



- The reliability of using composite wrap on the sensor gauges was performed using external impact test
- After impact, the sensors are still available to take data and effective for damage detection and corrosion monitoring

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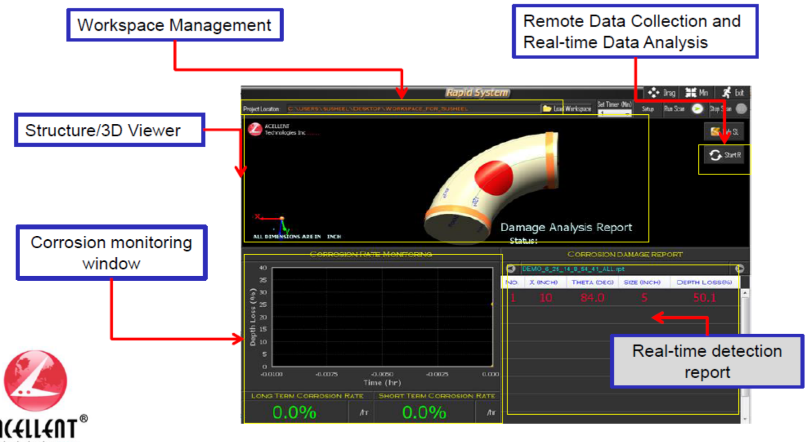
Task 7. Software Development



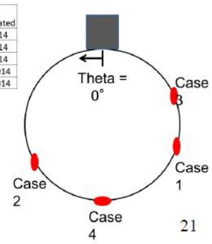
Task 8. System Test

- Laboratory tests were performed in Acellent to verify the sensitivity on the damage size
- Deployed RAPID system at PG&E Advanced Technology Service center at San Ramon for bird-grinded blind tests
- The results from blind tests were summarized and compared with PG&E's laser 3d imaging system.

Results Summary

	X (in)	Theta (Deg)	Diameter (in)	Depth (%)	Date Created
Case 1a	5.5	247.8	1.17	13.21	6/3/2014
Case 1b	5.9	254.0	1.5	25.35	6/6/2014
Case 2	6.6	121.6	1.5	19.12	6/6/2014
Case 3	6.3	286.0	1.4	16.97	7/24/2014
Case 4	5.5	178.4	1.6	11.43	7/24/2014

- Four damage cases were detected
- Cases 1 and 2 are known cases with added damage being made to Case 1 on 6/6/2014
- Cases 3 and 4 are predicted cases based on the results of the data collected from the SHM system



Video: PG&E In-field RAPID Demo

See Video

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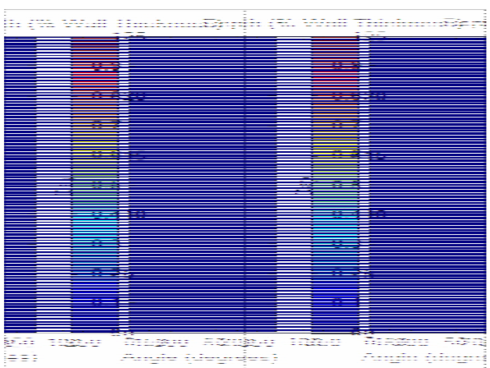
Time-Lapse of Damage on PG&E Pipe



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Additional tests requested by PG&E prior to technology transfer

- To test the effectiveness of the RAPID system in the presence of the most attenuated coating currently used in pipeline corrosion protection schemes (Asphaltic coating).
- To demonstrate the capabilities of the RAPID system to operate in an underground environment.
- Determine the effect of the presence of soil on signal attenuation
- Estimated time: 4-5 months. Need additional funds to support.

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Task 9. Technology Transfer

- Acellent is current working with PG&E to identify the critical prime area of interest for 24x7monitoring component in the gas pipeline system
- Acellent has identified potential collaborative private sectors in risk management industry to implement 24x7 inspection mechanism for gas pipeline risk management
- Acellent continues to work with risk management industry to scale up the impact to the gas pipeline safety by applying advanced real-time monitoring sensing techniques

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Task 1: Administration- Product List

No	Products	Due Date	Status	Submission Date
1	kick-off Meeting	7/16/13	Submitted	7/16/13
2	Report, List of Requirements	9/2/13	Submitted (included in Interim Reports of sensor and hardware)	1/30/14
3	Report, Sensor Optimal Design	10/30/13	Submitted	1/30/14
4	Interim Report, Hardware Development	1/31/14	Submitted	2/28/14
5	Final Report, System Reliability	3/3/14	Complete	2/15/15
6	Final Report, System Level Design	3/3/14	Complete	2/15/15
7	Interim Report, Software Development	4/2/14	Complete (to be combined with Final Report submission)	2/15/15
8	Final Report, Software Development	6/3/14	Working	2/15/15
9	CPR Report	6/3/14	Working	2/15/15
10	Interim Report for System Validation in Coupon Level	10/1/14	Complete	3/15/15
11	Final Report for in-field Demonstration	1/30/15	Working	3/15/15
12	Draft Data Analysis Report	1/30/15	Complete (to be combined with final data analysis report)	3/15/15
13	Final Data Analysis Report	1/30/15	Working	3/15/15
14	Draft Technology Plan	4/1/15		4/1/15
15	Final Technology Plan	6/2/15		6/2/15
16	Draft Readiness Plan	6/30/15		6/30/15
17	Final Readiness Plan	7/30/15		7/30/15
18	Monthly Progress Reports	30th each mo.	Submitted by Due	Each mo.
19	Final Outline of the Final Report	2/16/15	Working	1/30/15
20	Draft Final Report	4/6/15		4/6/15
21	Final Report	6/30/15		6/30/15

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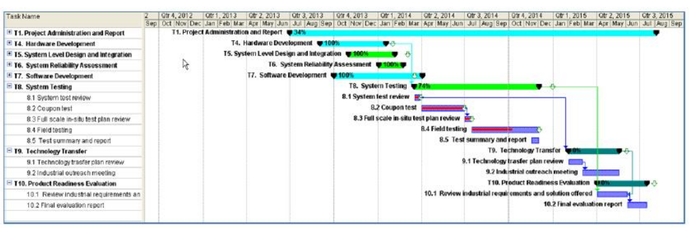
Project Execution & Budget Summary



Budget Amt.	Remaining Balance	Task	% Funds Expended to Date
62,262.00	26,067.10	Task 1	58%
31,131.00	1.83	Task 2	100%
49,810.00	687.46	Task 3	99%
124,524.00	9,005.01	Task 4	93%
56,036.00	264.35	Task 5	100%
68,488.00	1,255.08	Task 6	98%
74,715.00	-	Task 7	100%
124,524.00	3,733.25	Task 8	97%
15,556.00	10,222.37	Task 9	34%
15,566.00	15,566.00	Task 10	0%
622,612.00	66,802.45	Total	89%

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Remaining Tasks

- Technology Transfer
  - Working with PG&E to prepare technology transfer plan
- Product Readiness Report
- Final Report
- Final Meeting

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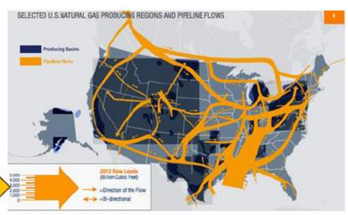
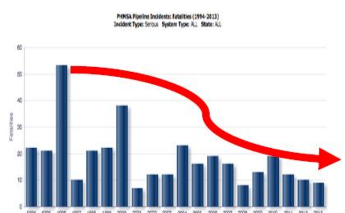
Concluding Remarks

Advanced Technologies, such as RAPID, PIG, etc. can significant reduce the risk of unexpected accidents of gas pipeline systems





Social Economic Benefits:

- Utility facility safety
- Economic Growth from sustainable energy

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Future Plan

- Acellent is planning to address PG&E's recommendation on pipe coating and underground condition tests
- We identified the usefulness of pipeline inspection technology depends on the integration with the risk management sector
- Gas pipeline system safety cannot be solely dependent on the inline inspection technology, it also requires the fast on-line screening sensor that can immediately report to the risk management system once incident event occurs

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Discussion and Questions

- Thank you.

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