University Transportation Research Center - Region 2

Final Report

Requirements, Model and Prototype for a Multi-Utility Locational and Security Information Hub

Performing Organization: New Jersey Institute of Technology

November 2015

Sponsor:
University Transportation Research Center - Region 2

University Transportation Research Center - Region 2

The Region 2 University Transportation Research Center (UTRC) is one of ten original University Transportation Centers established in 1987 by the U.S. Congress. These Centers were established with the recognition that transportation plays a key role in the nation's economy and the quality of life of its citizens. University faculty members provide a critical link in resolving our national and regional transportation problems while training the professionals who address our transportation systems and their customers on a daily basis.

The UTRC was established in order to support research, education and the transfer of technology in the field of transportation. The theme of the Center is "Planning and Managing Regional Transportation Systems in a Changing World." Presently, under the direction of Dr. Camille Kamga, the UTRC represents USDOT Region II, including New York, New Jersey, Puerto Rico and the U.S. Virgin Islands. Functioning as a consortium of twelve major Universities throughout the region, UTRC is located at the CUNY Institute for Transportation Systems at The City College of New York, the lead institution of the consortium. The Center, through its consortium, an Agency-Industry Council and its Director and Staff, supports research, education, and technology transfer under its theme. UTRC's three main goals are:

Research

The research program objectives are (1) to develop a theme based transportation research program that is responsive to the needs of regional transportation organizations and stakeholders, and (2) to conduct that program in cooperation with the partners. The program includes both studies that are identified with research partners of projects targeted to the theme, and targeted, short-term projects. The program develops competitive proposals, which are evaluated to insure the mostresponsive UTRC team conducts the work. The research program is responsive to the UTRC theme: "Planning and Managing Regional Transportation Systems in a Changing World." The complex transportation system of transit and infrastructure, and the rapidly changing environment impacts the nation's largest city and metropolitan area. The New York/New Jersey Metropolitan has over 19 million people, 600,000 businesses and 9 million workers. The Region's intermodal and multimodal systems must serve all customers and stakeholders within the region and globally.Under the current grant, the new research projects and the ongoing research projects concentrate the program efforts on the categories of Transportation Systems Performance and Information Infrastructure to provide needed services to the New Jersey Department of Transportation, New York City Department of Transportation, New York Metropolitan Transportation Council , New York State Department of Transportation, and the New York State Energy and Research Development Authorityand others, all while enhancing the center's theme.

Education and Workforce Development

The modern professional must combine the technical skills of engineering and planning with knowledge of economics, environmental science, management, finance, and law as well as negotiation skills, psychology and sociology. And, she/he must be computer literate, wired to the web, and knowledgeable about advances in information technology. UTRC's education and training efforts provide a multidisciplinary program of course work and experiential learning to train students and provide advanced training or retraining of practitioners to plan and manage regional transportation systems. UTRC must meet the need to educate the undergraduate and graduate student with a foundation of transportation fundamentals that allows for solving complex problems in a world much more dynamic than even a decade ago. Simultaneously, the demand for continuing education is growing – either because of professional license requirements or because the workplace demands it – and provides the opportunity to combine State of Practice education with tailored ways of delivering content.

Technology Transfer

UTRC's Technology Transfer Program goes beyond what might be considered "traditional" technology transfer activities. Its main objectives are (1) to increase the awareness and level of information concerning transportation issues facing Region 2; (2) to improve the knowledge base and approach to problem solving of the region's transportation workforce, from those operating the systems to those at the most senior level of managing the system; and by doing so, to improve the overall professional capability of the transportation workforce; (3) to stimulate discussion and debate concerning the integration of new technologies into our culture, our work and our transportation systems; (4) to provide the more traditional but extremely important job of disseminating research and project reports, studies, analysis and use of tools to the education, research and practicing community both nationally and internationally; and (5) to provide unbiased information and testimony to decision-makers concerning regional transportation issues consistent with the UTRC theme.

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Principal Investigator(s):

Fadi A. Karaa, Ph.D
Associate Professor of Critical Infrastructure
New Jersey Institute of Technology
John A. Reif, Jr. Department of Civil and Environmental Engineering
Colton Hall Room 274
Newark, NJ 07102-1983
Email: karaa@adm.njit.edu

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New Jersey Institute of Technology

Sponsor:
University Transportation Research Center (UTRC)

To request a hard copy of our final reports, please send us an email at utrc@utrc2.org

Mailing Address:

University Transportation Reserch Center
The City College of New York
Marshak Hall, Suite 910
160 Convent Avenue
New York, NY 10031
Tel: 212-650-8051
Fax: 212-650-8374
Web: www.utrc2.org

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Tierra Fisher*: Office Assistant*

Bahman Moghimi*: Research Assistant;*
Ph.D. Student, Transportation Program

Wei Hao*: Research Fellow*

Andriy Blagay: *Graphic Intern*

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16. Abstract

This project lays the foundation for building an exchange hub for locational and security data and risk assessment of potential excavation work. It acts primarily at 2 stages: upstream of the mark-out process, as a decision support tool to help streamline, improve and guide the mark-out process, and downstream of the mark-out to gain and preserve information gained from such field verified data, and added intelligence to each utility asset management system related to the potential proximity of other utilities, and possible criticality of proposed construction activity in a given site that puts at risk key assets.

Open to State DOT's, utility operators, One-Call System and regulators for planning infrastructure work and mark-out, this new information hub can also help guide emergency excavation work to be performed without the luxury of a detailed mark-out process. It can also provide critical sub-surface engineering (SUE) data required for planning and executing the highly uncertain and volatile utility relocation component of transportation infrastructure projects.

Using interviews, systems analysis and other analytical methods, the project key deliverables include:

1-Functional Requirements Document, based on user needs.
2-Development of System Upstream and Downstream Functionality.
3-Development of Integrated Data Model and Interface Categories for integration of multiple sources of data.
4-Definition of Communication Protocols for Preservation of Intra-Utility and Inter-Utility Exchange Capabilities.
5-Development of Prototype for Information Exchange Hub, using representative lifeline Utilities.

This project directly and indirectly meets the following USDOT Strategic Goals:
- Safety of Transportation system and the general population
- State of Good repair, as it supports the repair and reconstruction of transportation infrastructure, including underground utilities.
- Economic Competitiveness, based on the orderly expansion of infrastructure Systems.

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EXECUTIVE SUMMARY

Even if they are hosted in sophisticated GIS systems, the asset management systems maintained by various utilities are often plagued by information incompleteness and inaccuracy. The locational information is often based on approximate design data that differ from actual "as-built" drawings that may not even be held by such utilities owning and maintaining underground lifeline infrastructure systems (water, wastewater, electric/power, gas, stormwater, and communications networks).

This project lays the foundation for building an exchange hub for locational and security data and risk assessment of potential excavation work. It acts primarily at 2 stages: upstream of the mark-out process, as a decision support tool to help streamline, improve and guide the mark-out process, and downstream of the mark-out to gain and preserve information gained from such field verified data, and added intelligence to each utility asset management system related to the potential proximity of other utilities, and possible criticality of proposed construction activity in a given site that puts at risk key assets.

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- Economic Competitiveness, based on the orderly expansion of infrastructure Systems.

- Livable Communities, with appropriate levels of service of infrastructure.
- Environmental Sustainability, which is strongly dependent on the proper functioning of water, wastewater and stormwater networks.

It also falls directly within 2 of the defined focus areas of USDOT Region 2, namely:

1. "Infrastructure design, monitoring, inspection, and management to ensure a State of Good Repair", and
2. "System modernization through implementation of advanced information technologies".

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1. RESEARCH BACKGROUND

Much of what we rely on in our everyday life is routed through underground infrastructure systems, providing consumers, businesses and government with power, gas, water and communication services, as well as a host of environmental benefits. While this essential infrastructure link to the end user lies under or in close proximity to the transportation system, a good part of it is ill defined, catalogued or inaccurately located in a sparse set of information systems and sources.

Major State Departments of Transportation in the Region operate and maintain networks of thousands of miles of conduits, many carrying fiber optic cables that are vital to State communication systems. These conduits are located alongside highways and frequently must be located and marked to avoid damage from digging or boring resulting from construction. These conduits are part of a complex maze of facilities which also include important nodes such as junction boxes where fiber optic cables get re-routed from one conduit segment to another. Additionally, other private and public utilities (gas, power, water, wastewater, etc.) own and maintain networks of pipes and conduits in various vertical and horizontal proximities to one another at different geographic locations along, across or under roadways, highways and throughways. The location information accuracy varies from one utility to the other, and the exchange of such information across agencies and utilities is often hindered by data security issues, and related corporate policies.

Any maintenance or construction activity related to a particular stretch of conduit for a specific utility in a particular area, or to general highway re-construction or maintenance requires several special field investigations for the accurate location and mark-out of various utilities which assets may be impacted by such an activity. That is why, for any planned excavation activity, a work order has to be issued for various utilities to mark out the location of their separate systems before the work can be allowed to proceed under the guidelines of the damage prevention system. However, mark-out processes are inefficient, and rarely result in improved data accuracy from site investigation. Moreover, in unplanned emergency situations, the lack of locational data may result in dangerous digging and major accidents that imperil public safety.

The planning and scheduling of the safe undertaking of often critical work can only be done once the exact location of underground utilities has been established and ascertained. As infrastructure renewal is on the rise, and in an area long considered a major transportation and infrastructure hub, the lack of ad-hoc capability for identifying and accurately locating underground systems of nodes and links is bound to add significant inefficiencies and repeated field investigations, and increase the risk of significant damage in the case of work emergencies.

Even if they are hosted in sophisticated GIS systems, the asset management systems maintained by various utilities are often plagued by information incompleteness and inaccuracy. The locational information is often based on approximate design data that differ from actual "as-built" drawings that may not even be held by such utilities owning and maintaining underground

lifeline infrastructure systems (water, wastewater, electric/power, gas, stormwater, and communications networks).

Moreover, in most of the hazardous pipeline sectors, such as gas pipeline transmission systems, and gas pipeline distribution systems, the incidence of accidents (significant incidents) due to excavation represents a high ratio of the total number of such incidents, about 36% in the case of gas distribution systems (Figure 1). For these excavation related incidents, research showed that a large percentage was due to excavator errors, while a significant percentage was attributed to erroneous mark-outs.

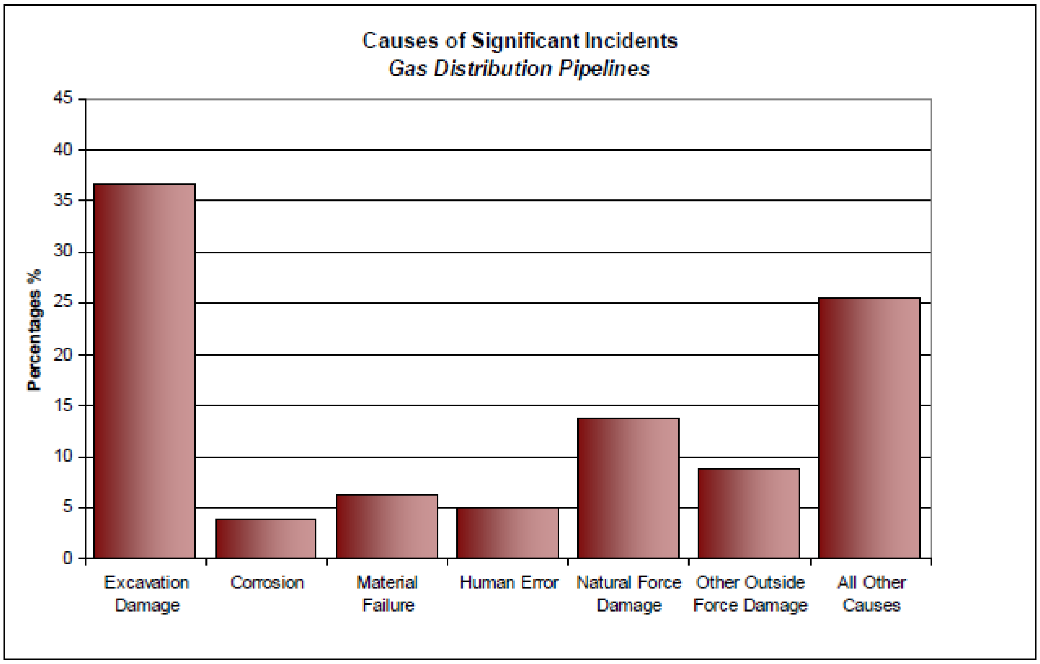

Figure 1. Causes of Significant Pipeline Incidents on Gas Transmission Pipelines from 1988-2008
Source: DOT/PHMSA Pipeline Incident Data

For the period of 1998 to 2008, PHMSA data also shows a large portion (26% of all 5,960 events) of the total significant incidents in both onshore and offshore gas pipelines to be traceable to excavation work.

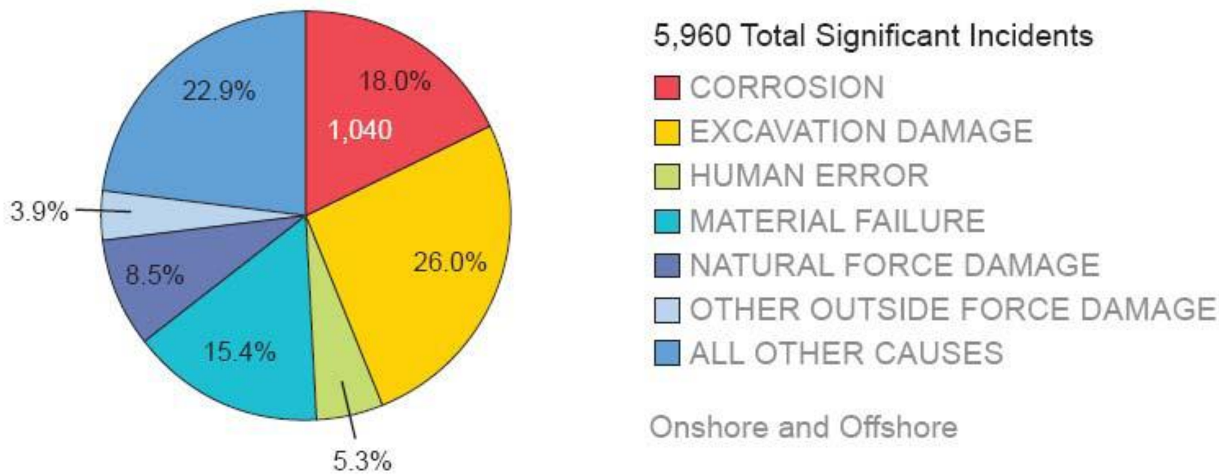

Figure 2. Excavation largest cause of onshore and offshore Gas Pipelines incident from 1988-2008
Source: DOT/PHMSA Pipeline Incident Data

This project lays the foundation for building an exchange hub for locational and security data and risk assessment of potential excavation work. It acts primarily at 2 stages: ***upstream*** of the mark-out process, as a decision support tool to help streamline, improve and guide the mark-out process, and ***downstream*** of the mark-out to gain and preserve information obtained from such field post-excavation verified data. It also provides added intelligence to each utility asset management system related to the potential proximity of other utilities, and possible criticality of any future proposed construction activity in a given site that puts at risk key assets.

Open to State DOT's, municipalities/utility operators, excavators and One-Call System and regulators for planning infrastructure work and mark-out, this new information hub can also help guide emergency excavation work to be performed without the luxury of a detailed mark-out process. It can also provide critical sub-surface engineering (SUE) data required for planning and executing the highly uncertain and volatile utility relocation component of transportation infrastructure projects.

This project directly and indirectly meets the following USDOT Strategic Goals:
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- Environmental Sustainability, which is strongly dependent on the proper functioning of water, wastewater and stormwater networks.

It also falls directly within two of the defined focus areas of USDOT Region 2, namely:

"Infrastructure design, monitoring, inspection, and management to ensure a State of Good Repair", and "System modernization through implementation of advanced information technologies".

1.1. Project Objectives and Relationship to Safe Digging and Modernization of Information Technologies

This project aims at defining the functional requirements, identifying data sources, developing an integrated data model open to all utility source information, and building a prototype using one and possibly more key utilities for a multi-utility information hub in support of field mark-out activities, that augments on demand intra-utility information sources and inter-utility exchanges, in order to achieve two key objectives:

- Improved support for infrastructure projects to keep the networks in a State of good repair, and in response to needed single or multi utility improvements. This is achieved through the provision of an information backbone and an ad-hoc tool for safe-digging processes such as the New Jersey One Call.

- Improvement and Modernization of Key Information Technologies for the Location and the securitization of the underground infrastructure systems attached to surface transportation, and the analysis and rating of the safety and security of planned construction and maintenance activities.

In particular, this information hub would be open to utility operators, excavators and regulators and have well-defined secure interfaces to the utility locational systems and data. As a decision support tool, it could potentially:

- For State DOT's and utility operators, access the list of their assets (links and nodes), within the vicinity of the intended excavation, and other data such as imaging and other technique outputs and as a background information to be verified by field investigations.
- For excavators, it would provide a general and specific assessment of the relative safety of the intended work, vis-à-vis all utilities and every impacted utility, and thus provide guidance for the level of attention and special care needed in undertaking such work.

1.2. Project Scope

The proposed project scope includes the following tasks:

Task 1 – Requirements Analysis (DOT, Utility, Excavators data needs, interfacing and functional requirements): Survey, investigate and propose all user requirements and functionality (DOT's, Board of Utilities, Utilities, Excavators, etc.) surrounding the objectives of the project in support of the location process and a possible re-engineering of its data sources, access and exchange capabilities;

Task 2 – Data Model: Development of Comprehensive Exchange Hub Data Model: integrated data model for the location and security information exchange hub will be developed to enable access to important information and its distribution by its "requester";

Task 3 – System Design: Work Flow for User Types and relations and System Screen Flows: Preliminary system design will be developed to cover the functional requirements, query types, and possible calculated fields related to proximity and risk ratings associated with excavation scope and types;

Task 4 – Prototype Development: Develop Programs for Data Access, and Multi-Faceted Query and Analysis: Coding of the prototype system, including basic multi-user capabilities, access data structures, sample and open access interfacing programs to selected utilities;

Task 5 – Validation: Develop Sample Data and test Program Flow and Validate Procedures: Validation of the system procedures through a set of data obtained from select utilities and State DOT's, converted for system use, and related to past and intended future highway construction jobs, impacted utility assets, and associated information types;

Task 6 – Documentation of the Research and System Development Project

Using interviews, systems analysis and other analytical methods, systems design and development, the project key deliverables include:

1-Functional Requirements Document, based on user needs.
2-Development of System Upstream and Downstream Functionality
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2. PROCESS AND USER REQUIREMENTS ANALYSIS AND DOCUMENTATION

The scope of the current report is the analysis and development of user requirements. The main focus of the requirements has been on the main categories of users capable of providing an input to the accurate location of underground utility pipelines, both pre and post excavation. To that end, a range of users from utilities, excavators and subsurface utility consultants/contractors were interviewed, using a questionnaire tailored to the scope of their work and their contractual obligations and potential liabilities.

In order to achieve the most detailed requirements analysis, the following concurrent tracks were pursued:

1- An understanding of the current One-Call type support of pre-excavation mark-out and post-excavation administrative procedures, across some of the major States with well-known records of safety and process documentation.
2- The review of best practices related to One-call process development and implementation
3- The development and implementation of a tailored questionnaire, which was used in interviews across a range of utility sectors and organizations who subscribe to the support of mark-out requirements.

After reviewing best practices and undertaking a number of interviews with various stakeholders, it has become apparent that the level of accuracy of the mark-out process across all utilities can influence not only the safety and cost-effectiveness outcome of the excavation job itself, but also of future mark-out interventions in that specific geographic location. An accurate mark-out can lead to an improvement of the location information in the asset management systems, which can enhance data records available for future requests for excavation. It is therefore critical to put in place a data acquisition and analysis capability that can help improve the conditions of the mark-out process, including pre-mark-out (upstream), and post-mark-out (downstream), in order to provide a full feedback on the accuracy of the actual location of the pipeline as well as the effectiveness of the mark-out task.

2.1. Documentation of Current One-Call Process: Advantages and Drawbacks

Realizing the effects that an accident can cause, a system called One Call was developed which facilitates the communication between the excavator and the utility operator. This has helped the excavator in a way that at least the independently or expertly identified mark-out of the location of the underground utilities with assets at the site, was marked in or around the proposed excavation site.

However it is important to note that, even after having such a facility in place, the accidents are still occurring. This can be seen from the example mentioned here. A UNCC (Utility Notification Center of Colorado 2005) study stated that 55.7% of the 9,371 incidents in Colorado in 2005 took place even though the excavators followed the One-Call procedures.

As an example of a One-Call process, the New Jersey Legislature "finds and declares that damage to underground facilities caused by excavation and the discharge of explosives poses a significant risk to the public safety; that such damage to underground natural gas facilities poses a substantial risk to the public safety; and that the implementation of a comprehensive One-Call Damage Prevention System can substantially reduce the frequency of damage caused by these activities".

As a confirmation of the dual responsibility of the operator and the excavator, the Legislature therefore determines that it is in the public interest for the State to require all operators of underground facilities to participate in a One-Call Damage Prevention System and to require all excavators to notify the One-Call Damage Prevention System prior to excavation or demolition.

As the regulator appointed by the Legislature, the Board of Public Utilities has designated the operator of, and provided policy oversight to, the One-Call Damage Prevention System and is in charge of enforcing the provisions of this act.

In order to shed some detailed light on the One call process, with its advantages and some drawbacks, it is important to start with some terms and definitions, as reported by the Board of Utilities Act on Underground facilities protection (3).

"Damage" means any impact or contact with an underground facility, its appurtenances or its protective coating or any weakening of the support for the facility or protective housing, including, but not limited to a break, leak, dent, gouge, groove, or other damage to the facility, its lines, or their coating or cathodic protection;

"Emergency" means any condition constituting a clear and present danger to life, health or property caused by the escape of any material or substance transported by means of an underground facility or the interruption of a vital communication or public service that requires immediate action to prevent or mitigate loss or potential loss of the communication or public service, or any condition on or affecting a transportation right-of-way or transportation facility that creates a risk to the public of potential injury or property damage;

"Excavate" or "excavating" or "excavation" or "demolition" means any operation in which earth, rock, or other material in the ground is moved, removed, or otherwise displaced by means of any tools, equipment, or explosive, and includes but is not limited to drilling, grading, boring, milling to a depth greater than six inches, trenching, tunneling, scraping, tree and root removal, cable or pipe plowing, fence post or pile driving, and wrecking, razing, rending, or removing any structure or mass material, but does not include routine residential property or right-of-way maintenance or landscaping activities per-formed with non-mechanized equipment, excavation within the flexible or rigid pavement box within the right-of-way, or the tilling of soil for agricultural purposes to a depth of 18 inches or less;

"Excavator" means any person performing excavation or demolition and may include a contractor having oversight for an excavation or demolition to be performed by rented, operated equipment under the contractor's on-site direction provided the contractor contacts the One-Call Damage Prevention System in the contractor's name, thereby assuming responsibility and liability, to give notice of the intent to engage in excavation or demolition work in that manner;
"Hand digging" means any excavation involving non-mechanized tools or equipment, including but not limited to digging with shovels, picks and manual post-hole diggers;

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BEST TIME TO CALL BACK
EXCAVATOR
EXCAVATOR ADDRESS
WORK DONE FOR
ADDRESS PHONE NO.
DIG LOCATION
MUNICIPALITY STREET ADDRESS
NEAREST INTERSECTION
TYPE OF WORK DEPTH
EXTENT OF WORK
START DATE START TIME

TIMEFRAME MATRIX

MON.	TUES.	WED.	THUR.	FRI.	SAT.	SUN.	MON.	TUES.	WED.	THUR.	FRI.
CALL -	MARKOUT	MARKOUT	MARKOUT	DIG							
	CALL -	MARKOUT	MARKOUT	MARKOUT	DIG*	DIG*					
		CALL -	MARKOUT	MARKOUT	•	•	MARKOUT	DIG			
			CALL -	MARKOUT	•	•	MARKOUT	MARKOUT	DIG		
				CALL -	•	•	MARKOUT	MARKOUT	MARKOUT	DIG	
					CALL -	•	CALL -	MARKOUT	MARKOUT	MARKOUT	DIG
						CALL -	CALL -	MARKOUT	MARKOUT	MARKOUT	DIG

* Contractors option to dig on Saturday or Sunday
•Holidays and Saturdays/Sundays do not count in three business days allowed for markout.
- Any request received at One-Call Center on a Holiday, Weekend or after 5 p.m. on a business day, is considered requested the next business day.

New Jersey State Holidays
New Year's Day
Lincoln's Birthday
Good Friday
Independence Day
Columbus Day
Veteran's Day
Christmas Day
Martin Luther King, Jr.'s Birthday
Washington's Birthday
Memorial Day
Labor Day
Election Day
Thanksgiving Day

Figure 3. The NJ One Call Damage Prevention System Handout

The One Call Damage Prevention System is mainly an active administrator of the request for excavation within a limited scope description. It is also an intermediate communicator between the excavator and the utility operator, setting some rules on the execution of the mark-out of various utilities and possible partial documentation of any reported incident resulting excavation work. The system is mandatory in most States. Every state with a similar approach has a dedicated One-Call system where utility operators and excavators are mandated to participate in it within guidelines of safety. No excavator can start digging before informing the One Call Damage Prevention System.

When the One Call System was developed, every utility operator was supposed to create a user account ID with the One Call System and provide it with the hierarchical location of their assets including list of municipalities and more detailed geographic areas and in some cases maps covering the complete Operator's underground facilities. This may include an alphabetical street index/GIS format with latitude and longitude for areas within a community in which the utility operates the underground utilities services. Based on this information, the One-Call System has the ability to request mark-out from utilities located on the vicinity of or represented in the area of the proposed excavation. In some cases, if the location information is too high-level (at the neighborhood or block level), the One-Call system may request mark-out from a utility that does not have assets in the vicinity of the excavation site. Requests for mark-outs are issued by e-mail, and billed as a transaction to the utility owner, in addition to the cost of the general subscription to the system.

One Call Process Description:
Whenever an excavator is proposing a site for excavation, he first opens a locate ticket with the One Call System at least 3 business days prior to excavation. Excavation should also commence no more than 10 business days after the ticket is issued (see Figure 3 above). In addition to his identification (name, phone numbers, email id and fax numbers), the excavator has to provide the purpose, scope and general location where the excavation is going to take place and his proposed start date of excavation. He then gets a confirmation number that remains open for a given period. Past that "open" period, if the excavation has not taken place, a new ticket has to be issued. For long term large excavation jobs, and in cases of delays in the mark-out process, the excavator may need to issue a number of separate sequential tickets, which may present an administrative burden, as well as a possible loss of information from one ticket to another.

A simple high-level process flow of the One-call system and its participants is shown below:

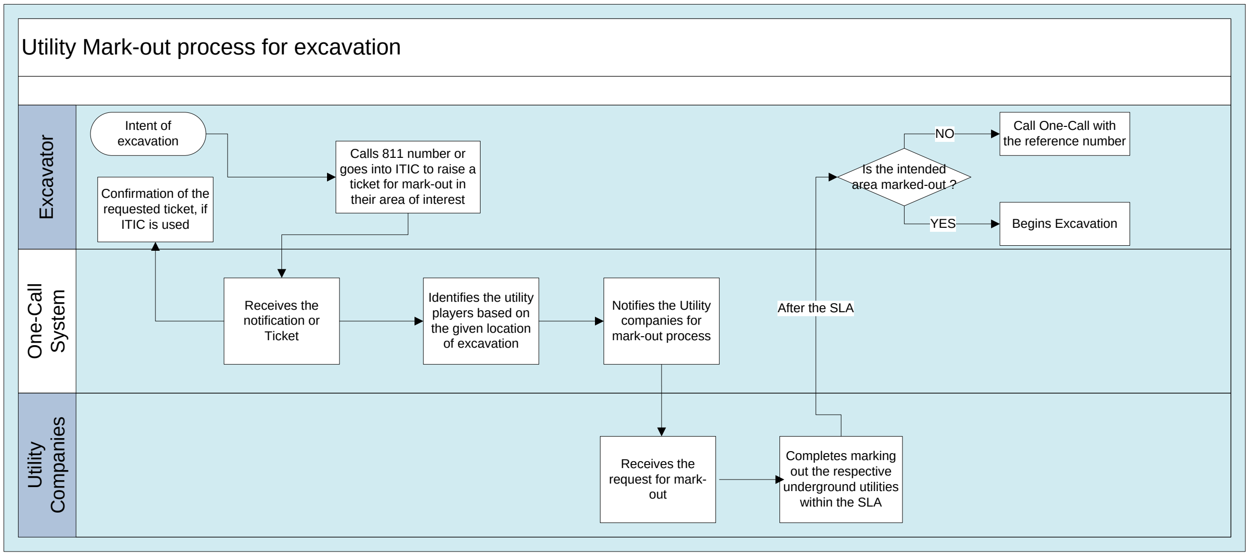

Figure 4. One-Call System High level Process Flow

The One Call System then notifies all the utility operators who have their utility in that particular location. It sends a full email notification of the request for mark-out documenting the excavation work (request for installation of gas service for PSE&G, with PSE&G acting as an excavator (force account)), and shown in Figure 5 below.

Table 1 summarizes the types of utilities and associated identifying colors for mark-out.

Utility Type	**Identifying Color**
Electric Power Distribution and Transmission	Safety Red
Municipal Electrical Systems	Safety Red
Gas Distribution and Transmission	High Visibility Safety Yellow
Oil Distribution and Transmission	High Visibility Safety Yellow
Dangerous Materials, Product	High Visibility Safety Yellow
Telephone and Telecommunications	Safety Alert Orange
Police and Fire Communications	Safety Alert Orange
Cable Television	Safety Alert Orange
Water Systems	Safety Precaution Blue
Slurry Systems	Safety Precaution Blue
Sewer Systems	Safety Precaution Green

Table 1. Types of utilities and associated identifying colors for mark-out

The impact of a possible job both in magnitude and severity (e.g. explosion of a gas pipe such in the San Francisco area in the recent past), or the timing of its effects (immediate versus delayed) depends on the careful execution of a script, which starts the process with hand excavation before a machine excavation (mechanical shovel) is allowed to be used in the excavation work.

Also, much of the current risk sharing is based on rather simple rules that postulate a level of accuracy within which each of the two parties potentially responsible for a possible accident may be exposed to contractual liability. In New Jersey, this rule simply states that if an accident is the result of an error in utility location, then if the mark-out falls within the acceptable "accuracy" requirements of the mark-out (a 4 foot wide band around the mark-out location, 2 feet on each side), the mark-out professionals are not liable and the excavation contractor would be liable. If on the other hand, an accident were to occur and the pipeline location was outside the 4 foot band, then the mark-out professional (if the service is provided by an external contractor) or the utility itself (if the mark-out service is provided by an internal technical team within the utility) would be liable for the "faulty" or inaccurate mark-out.

Current Upstream Processes: As a result of a possibly lengthy process of field investigations and corroboration with available sources of technical and electronic information, the mark-out of such utilities is undertaken, thus enabling the initiating request for action under safe digging guidelines to proceed. The mark-out of any utility within the required accuracy standards remains the utility operator's own responsibility, which it performs using the best of its internal data and field investigations. Each utility mark-out is in effect a "black box" with multiple sources of data from available records or field investigations, but where the steps undertaken are not independently verified. In case of error and if damage occurs, it will be the result of either an inaccurate mark-out or an excavation/construction activity gone beyond its intended geographic scope and boundaries.

Current Downstream Processes: If everything goes right, the mark-out locational data will most likely not be saved back to their respective source systems and be "discarded" after the excavation is completed. If a problem or accident arises, then the Act provides for assignment or apportionment of responsibility and liability. It seems that, at a time of expansion of digital information, a better decision support and information exchange tool supplementary and complementary to, but within the framework of the One-Call System would yield significant benefits to all parties involved including USDOT, State Departments and Agencies, excavators, and utility operators, as well as the public at large.

The One-Call system has the key advantage of creating an administrative system for preventing or mitigating damage resulting from excavation work. It can help enforce the rules of total participation by utilities and excavators in the mark-out process, and the prevention of "blind" excavation without prior mark-out.

Another advantage is the timeline for required to support both routine and emergency work and the notification system that ensures such prosecution of the mark-out work before any excavation can start.

However, the current system has some major drawbacks:

1- Due to the rules of engagement in the process, the focus is on the short-term task of providing the mark-out of all utilities by the utilities or assigned mark-out contractors rather than the long-term accuracy of the coordinates of the utilities.
2- If an excavator identifies a major discrepancy between the mark-out locations and the actual locations, he may notify the One-Call system and thus the utility of the discrepancy, although it is not an enforceable or controllable outcome.
3- If a "hit" resulting in a dent or damage does not result in an immediate incident, it may go unreported due to the requirements of the work progress.
4- The requirement of a different ticket after the expiration of the validity period makes it difficult to manage the accuracy of the excavation work relative to the mark-out coordinates on very large jobs that should be managed at the overall excavation performance level rather than the ticket level.
5- Most importantly, the mark-out coordinates and their accuracy or lack thereof, have an expiration shelf date beyond the job itself, which will lead to repeat mark-out requests at the same location for future excavation work, without the benefit of the identified and possibly modified or "corrected" coordinates.

Trusca, Viorel

From: nj@occinc.com
Sent: Friday, November 07, 2014 3:13 PM
To: Trusca, Viorel; Hung, Peter
Subject: ROUTINE 143111459

New Jersey One Call System SEQUENCE NUMBER 0018 CDC = NW2

Transmit: Date: 11/07/14 At: 15:13

*** R O U T I N E *** Request No.: 143111459

Operators Notified:
BAN = VERIZON CAN = CABLEVISION OF NJ
JOM = JOINT MEETING OF ESSEX & NW2 = NEWARK, CITY OF
PSHR = PUBLIC SERVICE ELECTRIC & XOC1 = XO NEW JERSEY, INC.

Start Date/Time: 11/14/14 At 07:00 Expiration Date: 01/15/15

Location Information:
County: ESSEX Municipality: NEWARK
Subdivision/Community:
Street: 220 SUNSET AVE
Nearest Intersection: 18TH AVE
Other Intersection:
Lat/Lon:
Type of Work: INSTALL GAS SERVICE
Block: Lot: Depth: 6FT
Extent of Work: CURB TO CURB. CURB TO ENTIRE PROPERTY.
Remarks:
Working For Contact: MARCO LOPES

Working For: PSEG
Address: 2000 FRANK E RODGERS BLVD S
City: HARRISON, NJ 07029
Phone: 973-430-3745 Ext:

Excavator Information:
Caller: MARCO LOPES
Phone: 973-430-3745 Ext:

Excavator: PSE&G
Address: 2000 FRANK E RODGERS BLVD S
City: HARRISON, NJ 07029
Phone: 973-430-3745 Ext: Fax: 973-482-7608
Cellular: 973-430-3745
Email: marco.lopes@pseg.com
End Request

1

Figure 5. Newark Water and Sewer Department Sample One-Call Ticket Notification

A realistic perspective on a multi-utility mark-out is shown below:

Figure 6. Multi-Utility Mark-Out Coordinates and identifiers
(Courtesy: http://brown.edu/Facilities/Facilities_Management/images/marking_utilities.jpg)

2.2. Researching Best Practices for Mark-out and utility information management

A Common Ground Study (CGS) was sponsored by the DOT in 1999 in order to identify and validate the best practices performed in order to prevent damage to the underground utilities. These practices were to be shared among various stakeholders to promote safe operations while working with underground utilities. After realizing the importance of such study, the Common Ground Alliance (CGA) was formed in order to continue the work of the CGS and to make the "Best Practices" document as informative and up to date as possible, in an effort to involve all stakeholders and avoid the unsafe practices. Moreover it uses icons for various stakeholders so that it is easy for them to identify their best practices and associated areas of responsibility in various phases and tasks. The 11.0 version of the Best Practices was published in 2014 (6). The relevance of the best practices to the upstream and the downstream processes of the One-call safe digging of the utilities, is presented next. Its implications for the One Call Center, the Process of Locating and Marking the utilities and the Excavators are also analyzed here.

a) Best Practices related to the One Call Centers (Upstream Process)

Documentation of Geographic Database Changes: In addition to general best practices related to the operation of the One-call center, a key best practice listed in (6) states that "the one call center returns the geographic description database documentation to the facility owner/operator annually and after each change for verification and approval."

This is one of the best recommended practices in the manual, and has multiple benefits from all stakeholder perspectives. In this manner, the One Call Center's data remains accurate and

consistent with the underlying utility data which is updated from time to time. The utility operators can cross check and make necessary changes. If they have closed any facility in a particular area and are still on the file, they will receive unnecessary tickets and will be charged. If they have any facilities added, updating them will provide them some surety against safe digging of the ground in that area.
It is implemented in some states, but it not to so easy to do. The implementation of the proposed hub can help alleviate the increased work load.

Organization of Meeting requests for Complex projects: Another stated best practice is that "The one call center has a process for receiving and transmitting requests for meetings between the excavator and the facility operator(s) for the purpose of discussing locating facilities on large or complex jobs." It would be beneficial for every party to plan a meeting for large complex jobs because it involves greater risks to the excavator's project and the facility's owner/ operator. Though involving the One Call Center would not be effective in every case because of the increased organizational and technical changes involved, it can be done within the scope of the proposed information exchange in order to limit the additional work load on the centers. But on the other side if it is a mandated requirement for large complex jobs, it would likely help avoid major accidents.

Multiple Points of Reference for Excavation Location Data: The one call center can accept multiple types of points of reference to define the exact location of an excavation site.

Incorporating this practice can yield much better results because the utility owner can expedite his process of locating his assets with multiple reference points. With the expedited process, the excavator can get the mark outs quickly. Having multiple reference points will ensure that all the utility owners are informed. There are a few centers that have incorporated this practice, but it can also be made a part of the upstream information exchange.

Discoveries after Excavation: The one call center has a defined and documented policy for handling calls from excavators regarding the discovery of an unidentified line.
It is also one of the best recommended practices, and should be incorporated in a broad asset location variance exchange capability. Also, the establishment of a proper procedure for unidentified lines will help in future damage prevention.

Maximum Locate Request Area: This best practice recommends that a maximum locate request area that is appropriate for a proposed excavation site is defined for a facility locate request.
In order to reduce complexity and improve accuracy, there should be a limit on size of the locate request. This will reduce uncertainty and the excavation area would be much more manageable.

This will also prevent unnecessary locator effort and prevent the possible fading of the markings with time if the work is not started as soon as the mark outs are done.
However, we believe that a proper information management of an excavation job can help segment the locate request into a number of "maximum" Locate request areas in order to make the work effort more manageable without losing control of the overall linkage between various "segments" of excavation, and the overall project performance.

b) Best Practices Related to the Location and Marking Process (Upstream Process)

Most of the best practices related to the location and marking upstream process aim at improving the completeness and accuracy of utility information, and their implementation depends on the owner or operator of the underground facility and their contracted subsurface engineering personnel.

Error and Omission Reporting: If a facility locator becomes aware of an error or omission, then the facility locator provides information for updating records that are in error or for adding new facilities.
This is particularly easy and efficient to implement within the scope of an information exchange. Making the correction protects the operator and the excavator from immediate and future damages caused to the utility.

Training of Operators: Proper locator training to the locator is essential to the quality of the upstream process and the generation of accurate mark-outs of the proper utilities and their relative positioning. Without proper training, the locator would mark wrong locations leading to accidents.

Positive response is provided to facility locate request: Any action taken by the locator or the operator on the locate request from the excavator will ensure that the operator is aware of the status of the proposed excavation and the possible pending need to mark out the facilities. This would require a dedicated time in some cases where the operator has to call the excavator, but would be even easier, more immediate and efficient within an exchange information structure.

Multiple facilities in the same trench are marked individually or with corridor markers:
In cases, where the total number of buried utilities are unknown but are in the same trench operator by the same owner, the corridor marker can be used in which only the width of the trench is known. It would be beneficial to use the corridor marker and mark out the whole width of the trench instead of being confused and marking the utilities wrong. Again, this would be

easy to maintain as a capability in a long-term full-fledged exchange information structure, which would identify such corridors for future excavation purposes.

The facility owner/operator is identified: It is very beneficial to allow the excavator to know if all facilities are marked or not, and proceed accordingly. It is also helpful in case of emergencies to locate the operator whose facility has been damaged. This is easy to implement and can be done by keeping the utility name in such a way that it is easily visible, or providing the status electronically via the exchange structure.

Documentation of work performed on a locate/mark-out request is maintained: This is one of the best practices that should be followed because it helps eliminate confusion over what work was requested by the excavator. It proves that a locate work order was performed and can be useful to the locator in cross checking that every utility was marked. However, this practice is mostly not followed. It is easy to implement within the scope of the proposed information hub and exchange

structure. Also, documentation can be kept through digital images that can be stored for future reference.

New facility Installations in Excavation Areas: Facility operators ensure that new or recently installed facilities in areas with continuing excavation activity are marked upon installation to indicate their presence.

Not following this recommendation can put the safety of the new facility at risk. It might be missed in the locate request because it might not have been documented in the operator's record. It is very easy to implement if the sourcing of information for the locator from the utility operator GIS or asset management system is updated as soon as an installation has taken place and as-built coordinates provided to the system. As a precaution, a utility operator who installs a new facility has to check if any excavation is being performed or not and the operator's documents should be updated as soon as possible.

c) Best Practices related to the Excavation Process (Downstream Process)

Many of the best practices mentioned in the document are described below. The implementation of these practices solely depends on the excavator unless stated as a rule.
Designation of Excavation Area: When the excavation site cannot be clearly and adequately identified on the locate ticket, the excavator designates the route and/or area to be excavated using white pre-marking prior to the arrival of the locator.

This practice is very easy to implement. Moreover, it is beneficial for the locator because the boundaries of the area to be marked are already defined.

Pre-Excavation Meeting or Other Coordination Requests: When practical, the excavator requests a meeting with the facility locator at the job site prior to marking the facility locations. Such pre-job meetings are important for major, or unusual, excavations and was mentioned above in the one-call center best practices. However, it can be made seamless with the presence of an information exchange hub for upstream/downstream processes, as the major impediment to its implementation lies within the required coordination to set up a meeting.

Also, in some cases, the excavator should coordinate work that requires temporary or permanent interruption of a facility owner/operator's service. The excavator should be informed ahead of that requirement. If for some work, the utility has to be shut off, the excavator has to coordinate with the operator. Also, the One Call Center should be notified about any such pre planning meetings.

Documentation of mark-outs: This is one of the important practices that should be followed in order to evaluate the accuracy of the mark-out versus the actual locations while the work is being performed, and in order to afford all parties with recorded at times of disputes and while the work is being done. Digital images are the best way to document it along with videos or sketches with distance from markings to fixed objects. We also believe that the availing of processes for location data collection after the excavation has commenced is critical, and can put some GPS and related location technologies to proper use.

Communication of Variance of Location Information (Mismarked facilities) or Incident Reports: In case of emergency such as damage or discrepancy between the marking and the actual location of the facility, efficient communication with the utility operator can expedite the resolution of the problem without major work interruptions, and is best implemented within an exchange structure.

Excavation Area Details: The excavator has to provide details about the excavation area location such as starting and ending points, the side of the property (north, south, east, west, front, back, rear, sides, etc.) and the side of the street. This is relatively difficult but can be facilitated with an information exchange structure.

As Built Documentation: It is highly recommended to follow this practice. If the contractors have installed the facility at a bit different location from the assigned one, he/she should inform the facility owner/ operator about the change and the correct position of the pipe. It is very easy to implement. The contractor will have to take the exact location and depict it in the as built drawings.

2.3 Data Sources and Support of Mark-Out Process

a) Locational Data Forms of Record Keeping:

Engineering Drawings: It is the traditional method to record any information which can be depicted by graphics. Mostly when the underground infrastructure was being developed, the records of the location of the utility were scaled on to a drawing sheet. The utilities were planned on to the drawing sheet first and then laid accordingly. These were the “as planned” drawings. Ideally, when the utilities are laid, their location again is sometimes redrawn on a different set of drawings called the “as built” drawings. These drawings show the actual location of the underground utilities. Many companies still follow this traditional method only; they have not converted their record to the more sophisticated CAD, GIS or BIM systems.

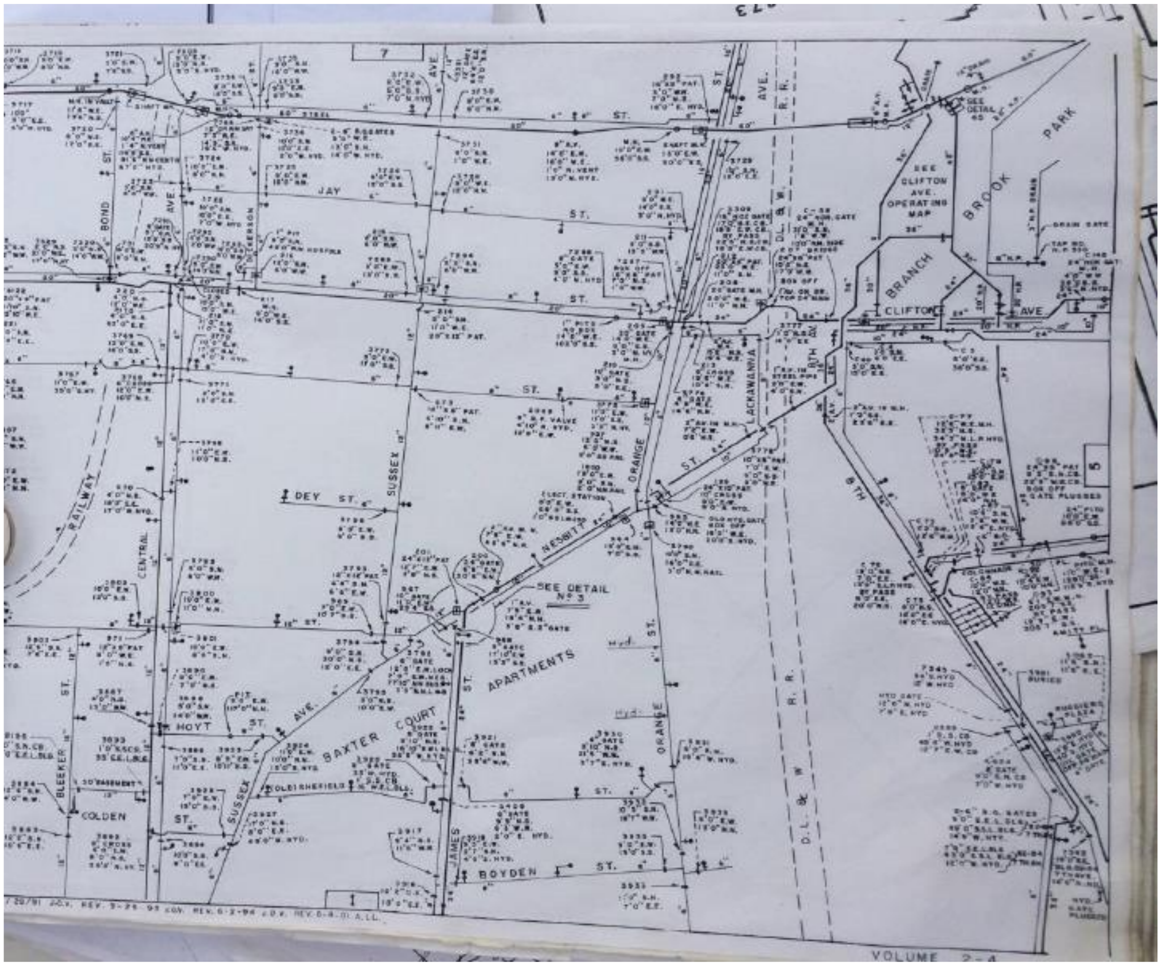

Figure 7. High Accuracy drawing of sewer lines location in the City of Newark, NJ

Geographic Information System and Asset management System (GIS) - A GIS is a computer system which is used to capture, store, edit, analyze, manage and present all geographical data. In this the hard copy plan or map is converted into a digital medium with the help of a CAD program and geo-referencing capabilities. The GIS coordinates can depict the reference as building address, street intersection etc. But the GIS accuracy depends on the main original data and proper updating of reference information as it changes, e.g. road widening, relocation, etc. Accuracy is improved if the data is derived from multiple reference points with proper digital GPS positioning. However, as the underground infrastructure is already developed, the companies have started the computerization of records by transferring the data from the drawings so the accuracy of the GIS coordinates itself is unreliable.

A number of probable reasons of the record/ data inaccuracy have been identified and include:

1) *Human error* while measuring or either noting down the location of the coordinates from the reference points.

2) *Lack of As-built drawings*: Sometimes only the "as planned" drawings are found and the actual "as built" drawings are missing or not formulated.

3) *Changes to the Infrastructure*: The changes made to the underground infrastructure of a utility operator's assets are not updated in the drawings.

4) *Modified or Shifted References*: With the change in reference infrastructure (road widening, relocation of services, etc.), the reference points will be changed and so when the marking out is done it might lead to a wrong location of the utility.

Hence, updating the information is a crucial thing that should be done so as to keep the location up to date for future excavation work. Generally this is not feasible without expensive investigative methods, because the utilities are buried underground. The one-call process augmented by an information exchange infrastructure can however help improve the accuracy by updating the location coordinates of their utility assets.

b) Utility Field Investigation Methods:
The utilities of interest may include lines for telecommunication, electricity distribution, natural gas, cable television, fiber optics, traffic lights, street lights, storm drains, water mains, and wastewater pipes. After the utility owner or operator receives a notification from the One Call Center, a check of corporate databases for the presence of any assets in the excavation site takes place. If there are any utilities present, they respond according to the type of service needed as routine or emergency. A locator from or on behalf of the utility operating company goes to the site where the markings are needed.

The locator should have with him a summary of the best available records related to their utility in that particular area. However, in practice, some basic information is provided by the least "sensitive" areas, such as water and sewer, while more detailed reference information may be provided for more hazardous areas such as gas lines. These records can be in the form of drawings or the data from the GIS/asset system in use as described in the section above.

The locator also has access to a range of equipment types which can locate the utility underground. The drawings can just be used as reference because with time there can be many changes in reference points or the location of the utility itself which have not been depicted in the drawing. Hence such technical equipment can help the locator finalize the position of the utility. A review and decision analysis of the most appropriate technique for detecting and locating underground conduits, including Modern Ground Penetrating

Radar (GPR), electro-magnetic induction, acoustic transmission and other radio location techniques can be found in Katz, Karaa and Niver (1).

Such investigative techniques, augmented by record keeping can help improve the mark-out process and lead to a more accurate location of the underground location compared to their actual location. This reduction in the margin of error, can reduce the probability of an incident, which includes both short-term major damage, and also damage that can have long-term consequences such as a damage to a water pipe.

2.4 Design and Implementation of a Multi-Stakeholder Questionnaire

A questionnaire was prepared keeping in mind the utility operators, the sub-surface engineers and utility locators, and the excavators. A set of questions were designed to identify the problems they face during the upstream or the downstream process of safe digging, the application of some of the best practices, and the relevance of some of the proposed implementation of an information exchange structure.

Many interviews were conducted, and some are still planned, concurrently with the future tasks of data modeling and system design. Representatives of a cross-section of utilities ranging from water and sewer (Newark Water and Sewer, and Princeton Public Works, NJ), as well energy (PSE&G and First Energy (JCP&L), multi-utility locators (Utiliquest) and excavators. A sample of two questionnaires are presented in this section.

a) Utility Operator’s Perspective: (Newark Water and Sewer Department, NJ)

Questions to the Utility Operators
Newark Water and Sewer Department.
Mr. Viorel Trusca- Principal Engineer/ Hydraulics
Mr. Peter Hung- Main Mark out Technician

1. How do you get the alert about the excavation that will be performed in future in the location where your utilities are present?

A. It is all through NJ One Call Damage Prevention System. It started in 1995, operated through fax. Now it is operated through emails/internet.

2. How do you respond to the alert?

A. From the given location in the alert, check from the drawings. Usually respond within 4 days from the ticket issued in routine categories. (There are two categories: Emergency and Routine)

3. What system do you use to store the location of your underground utilities?

A. It is all in the drawings/ maps. They are trying to upgrade it into GIS. The GIS will have data transferred from the drawings.

4. What do you give out the mark out people as reference i.e. drawings or records?

A. They have drawings as well as an instrument having a receiver and a transmitter device which can help locating the utility underground.

5. Does the mark out people take any kind of instrument with them through which they can mark out the precise location of the concerned utilities?

A. Yes, as mentioned before they take a transmitter and a receiver instrument with them. The receiver catches the frequency and responds.

6. Is there any record available of the depth information of the utilities?

A. Generally the water and sewer lines are at a depth below 4.5ft. The instrument does not give any accurate information about the depth of the utility.

7. After the mark out is done and the excavation starts, do you get any feedback on the accuracy of the location of the utilities? If yes, what is your next step?

A. Generally, our marked out utilities are correct. If we find that the instrument location and the location from the drawing doesn’t match, we correct it manually in the drawing itself. No feedback in most of the cases. In Newark, there is no major change so even the location of the utilities hasn't changed much. Also the water and sewer is mostly the bottom most utilities present underground.

8. Do you update the location in the system?
A. As answered, if we find any discrepancies in the locations from the instrument and the drawings, we do correct it manually with a pencil.

Some additional information converted to questions and answers.

9. How the NJ One Call System knows the utilities present in a particular area?
A. As in the case of Newark Water and Sewer, when the NJ One Call System started, they had to send their drawings/maps of the utilities. Information on how the NJ One Call System has stored the locations is not available.

10. Is the proposed excavation area marked out when you go to the location to mark out your own utilities?
A. No, the excavation area is not always marked out.

11. How many sets of drawings do your mark out man uses?
A. There are two sets of drawings: Main line and the Service line maps.

12. What are the main things to keep in mind while marking out? What are the best things important in the whole process?
A. The footage from service to service line is important. The important things for the whole process are every written document/ record, operating maps, service maps, location maps, subsurface maps (depth information might be available).

b) Excavator's Perspective: (Nordic Contracting, NJ)

Nordic Contracting – Mr. Jody Larson

1. How do you start the excavation process? / Whom do you inform about the upcoming excavation?
A. Definitely NJ One Call

2. Is any depth information of the utilities available from the mark outs?
A. Sometimes available, but not accurate.

3. What is the measurement of accuracy of the mark outs?
A. The utilities are allowed to be at a variance of 4 feet on either side of the mark outs done.

4. In case, it does not depict the exact location, then what is your next step? Do you inform any concerned agency?
A. No they don't inform any agency. Once the mark out is done they are free to excavate.

5. Do you note down anywhere for your records to avoid any liability issues?
A. We just keep the tickets of the One Call, nothing else.

6. In case you hit some underground utility, what do you do?
A. If it is not an emergency situation, we repair it on our own. We do not inform the concerned utilities. In case it is an emergency situation, then we have to inform them. We do whatever we can to fix the damage, if it is in our control.

7. Would you be amenable to helping collect the information on location of various utilities/pipes, if you were provided with electronic equipment to do that easily and swiftly?
A. No, we don't do that for living. We are quite busy and don't have time for such things, nor do we want to get into that.

Findings from the above interviews and others performed across stakeholders are as follows:

1) The One Call System is followed by each and every utility operator since it has started and was mandated by the law. They respond to the alert in the same way as required by the law. The follow the positive response approach.
2) While some utilities have a range of automated sources such as GIS data, it is mostly representative of the same level of accuracy as the paper drawings as they are rarely updated under the current mark-out processes, which are not conducive to feedback and due to the high costs. The Newark Water and Sewer Department, which still has the older yet accurate and updated drawings, is currently developing its GIS system for its utilities.
3) While the marking of the utilities, utilities provide some source of information to its locators, usually some reference data, which is more advanced in the case of sensitive utilities, with higher accuracy requirements. Locators are supposed to independently verify location of the utilities using the required investigation equipment/technique. The

equipment is typically a transmitter and receiver which locates the utility based on the maximum signal strength received.

4) Locator experience is critical, but if coupled with the source data, can yield the proper corrective action to the source data in the utility drawings and location databases. An information exchange that provides the locator this combined ability can help improve the mark-out accuracy.
5) Across all utilities, it was determined that the location process does not yield any meaningful or reliable depth information available from the equipment or the records. Such information can be obtained reliably after the excavation and should be quite useful for future excavation safety.
6) There is no feedback generally from the excavators unless a problem occurs; hence according to the utilities and their locators, their mark outs are correct. If they find any discrepancy while marking out in the drawing and the location shown by the equipment, some may rectify it or report it to their engineering departments.
7) The proposed excavation area is not always marked out as officially required. If this practice is not followed, then the locator might be wasting significant time and sometimes a part of the proposed excavation area might still be left out to mark.
8) The main comparative metric the locator keeps in mind is the footage from service to service line. On the whole, every written document/ record, operating maps, service maps, location maps, subsurface maps can be useful to accurately determine the location of the utilities. A system that can provide such information as needed to the locator can help improve the accuracy of the mark-out process and current and future safety records of excavation activities.

2.5 Summary of Findings from Interviews, best Practices and Literature

It seems from the questionnaires, the best practices and the literature reviewed that one of the leading cause of the accidents happening is the inaccuracy or incompleteness of records of information available about the location of the utility, including missing depth information and often unavailable as-built drawings due to the acquisition of a number of smaller utilities with outdated legacy location databases. However, it is a useful starting point for any thorough location effort. If updated as a result of the mark-out (upstream), and excavation location data identification, it can yield major improvements to the quality of location data and improve safety records during and after excavation.

Also, many a times the published Best practices are not followed even if they are easy to implement. Implementing the best practices listed above, which can be facilitated by providing an exchange hub for all the stake holders involved, can reduce the number of accidents greatly.

This exchange hub will serve purposes like the locational data and the risk assessments of potential excavation work involved. It would be of great help to the facility owners/ operators, the excavators and the One Call Centers.

It will work on both the sides: upstream side of the mark out process and downstream side of the mark out process. On the upstream side, it will work as a decision support tool in the process of marking of the utilities. It will make the mark out process easier and more efficient. On the downstream side, it can work with the excavators to acquire and store the information available at the time of excavation. It can also be helpful to know the positions and potential risks due to adjacent utilities. It will be open to the DOT's and can provide information to the Subsurface Engineers regarding the utilities so that they can assist in planning the relocation or construction part of the transportation projects.

For the locational information part of the exchange hub, improvements can be expedited in many ways. For the new utility assets which are being placed, their accurate position with the help of mobile GPS can be known. Images can be taken and stored in the corporate databases and reused in response to mark-out requests. The locational information can be converted to the GIS format and then made available on demand to the exchange hub.

For the old utility assets, which are already in place, their records might be missing information or they would likely be inaccurate. Utilities can gradually achieve the accuracy required by passing the tests of accuracy afforded by the exchange upstream/downstream feedback loop. Once the information accuracy is ascertained, it can be updated via the exchange hub into the native source systems maintained by various utilities. The actual location of the facility should be converted into the GPS coordinates and then can be communicated via the exchange hub. Hence, in this manner gradually the locational information of the complex network will be become more accurate over time, and will lead to reduced costs of mark-out and excavation and higher safety records.

The exchange system can yield the following additional benefits:

1) The planning process will become easier as the designers would actually know the location of the underground utility. If the planning/ designing is done after knowing the position of the underground utility, there will be no need for expensive change orders or delays to relocate the utility or to redesign the new utilities.
2) The information will be widely available and will be easy to use for the entire stake holders concerned. Hence, in case of discrepancy or confusion, the exchange hub will be able to give the most accurate information possible.
3) If any discrepancy is found in the location underground, or if at all any changes are made to the location underground, they can be updated in the exchange hub. Hence, the risk of

not updating is eliminated, given that all stakeholders would work towards the maintenance of the exchange hub and its purpose.

4) Due to the automation of communication and the collaborative nature of the information hub, minimal loss of productivity due to information discrepancy and reconciliation will be incurred due to the use of exchange hub.
5) The risks of proposed work can be known too, due to more accurate location information available on demand. The exchange hub would serve as a platform on which the excavator or the operator can update non locational information too regarding the utility.
6) The cost of building the exchange hub would be a onetime cost with some maintenance cost to keep it available to all parties, and will supplement the current One Call process. If implemented efficiently, it would be a fraction of the overhead, delay, repeat investigative mark-out and accident costs incurred under the current system.

3. SAFE EXCAVATION EXCHANGE SYSTEM DESIGN AND DEVELOPMENT

3.1 Documentation of the One-Call System "As-is" Business Processes

The review of the procedures described in the "Excavator Handbook for Damage Prevention", as well as the information gathered from interviews and/or site visits with a range of stakeholders (Excavators, Utilities, and mark-out professionals) allowed our research team to develop, beyond the High-Level work flow in Figure 4, a Business Process Diagram for the As-is processes of the One-Call System, shown in Figure 5. Although these processes might differ from one State to another, the roles of various process participants and their key interfaces are similar.

What is most notable about the current process, is that the One Call Server (OCS) acts as a pass-through of requests for Excavation from an individual excavator working in most cases on behalf of a utility owner or a public infrastructure owner. Once the request is logged into the system, with a Status of "Emergency" (Mark-Out to be performed asap for work to be performed within the next day) or "Regular" (Mark-Out to be completed within 3 business days).

The key role of the OCS after a request is initiated by phone or on-line, is to notify utility owners of the need to complete the mark-out of their assets. This "mark-out" ticket is performed by e-mail based on a facility identification system that is often sent to utilities located in the general area, but without the accuracy required to identify such utilities on a street level. Some of the utilities that are notified but so not have any assets, should report the absence of assets in order to better identify progress of the overall mark-out effort.

During the Upstream Process (Pre-Excavation Mark-out): For notified utilities that have assets in or in the vicinity of the excavation area, the mark-out process is then a black-box whereby, they would assign locators or mark-out professionals from their own force accounts or from contracted subsurface engineering consultants. The information provided to them in order to perform the mark-out is external to the OCS system, and the location of the assets resulting from the performance of the mark-out work remains also external to the system, and in most cases not collected in any automated system. Mark-out professionals would mark the lines with the appropriate color code, and leave the site. The accuracy of the asset location resulting from the mark-out as compared to the location information found in the utility systems and databases, cannot be ascertained, as there is no tracking or reporting mechanism of the two instances and their possible variances. At that stage, Utility Owners/Operators should notify the OCS system that their mark-out has been completed.

During the Downstream (Post-Excavation) Process: Once all mark-outs are performed, excavators are notified that they can commence excavation. Once excavation uncovers some of the utility assets, the actual location as identified visually or by contact is not stored or reported unless there is a major discrepancy in the asset location as compared to the mark-out location, or if a damage or incident has occurred due to such location error, resulting in a potential liability issue. In particular, information about pipe depths which is seldom known and recorded accurately by utilities, is not collected, stored and reported back to the respective utility owners.

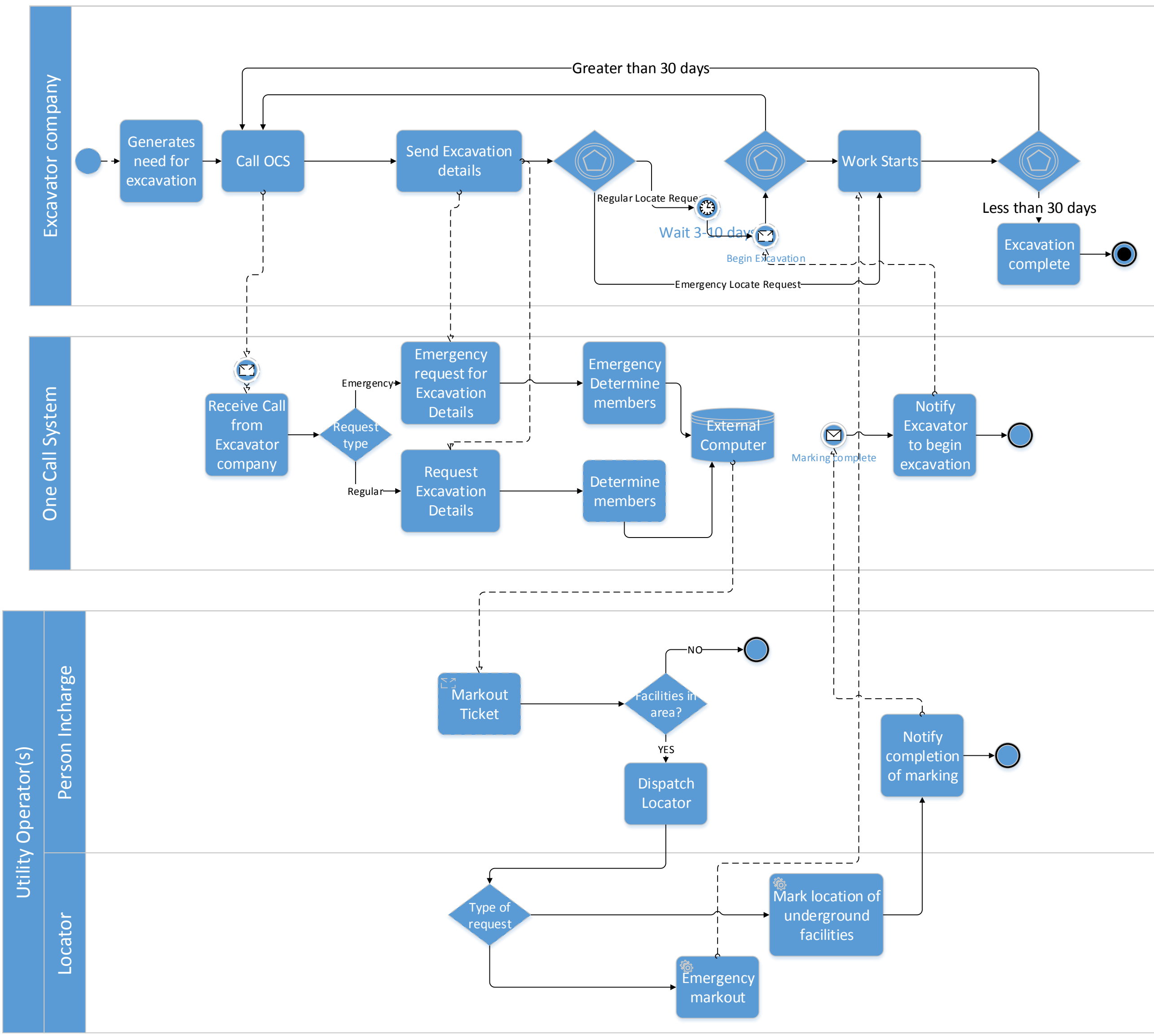

Figure 8. Business Process Diagram (“ As-Is”) - One-Call System

3.2 Safe Excavation Exchange System (SEES) Prototype "To be" Work flow and Sequence Diagram

The SEES prototype system creates an open yet controlled environment where 4 key Stakeholders are engaged in a process that is supportive of accurate mark-out and utility location information, and by the same token, of safe excavation. These Stakeholders and System Users, include the Excavator, the Utility Owner(s), the Mark-out Professional(s), and the System Administrator, who interact through the workflow described in this section, and further defined in the following sections in its underlying data model, system architecture and logical sequences. The System Administrator plays a more pro-active role in the enablement of the accuracy evaluation and location "correction" processes.

The "To-Be" process workflow as envisioned in the SEES system is therefore divided into the Pre-Excavation (Upstream) and Post-Excavation (Downstream) system tasks/transactions:

Upstream To Be Process Flow:

1- Work Ticket Creation and Excavation Area Site and Boundaries definition:

The Excavator logs in a work ticket request for excavation at a certain location. Scope of work is described, along with location of work and extent of work area. Location/extent of excavation area can be described by:

a- Address Range along a street dimension (e.g. from 1000 Main street Newark, NJ to 1214 Main Street Newark, NJ), as well as width/depth information which can be combination of distance to curb and width (e.g. starting from 20 feet to curb, and with a width of 15 feet), or a difference between 2 distances to curb (from 20 feet to curb to 35 feet to curb). This capability is

b- Location v/s Reference Points along the street dimension (e.g. starting from 10 feet North of Electric Pole (Asset Reference Number ###) located at about 980 Main Street Newark, NJ and extending to 15 feet South of Stop Sign (Asset Reference ###) located at about 1240 Main Street Newark, NJ), as well as width/depth information as in a) above

c- Polygon Representing the Excavation Area, which can be superimposed over a Google Map file representing the surrounding area, and saved in a picture field.

The SEES Prototype system functionality incorporates the Address range feature as described in a) of the excavation area definition, as well as a capability to add reference points for both excavation areas and asset locations, as shown in b) above.

In order to provide a system that enables a more accurate definition of the excavation area, the initiating work ticket should include, in addition to the general location of the work, as well as descriptive optional text for the site area, as precise a definition of the excavation area as can be ascertained from the work scope provided to the excavator. Such information can be obtained from the review of project drawings, as well as site surveys and walk-throughs.

2- Identification of Utilities with underground Assets directly in and in the vicinity of the Excavation Area:

Based on the work ticket above, (using a utility street reference lookup table for utility geographic presence with sample records containing fields such as Municipality, County, State, Street Name, (optionally also: Street # from, Street # To), Zip Code, Utility Name, Infrastructure Type, etc. as for example, the utilities with asset presence in the excavation area are identified. For example, for a hypothetical excavation area taking place within the range of the imaginary location of 226 to 248 Main street, Newark, NJ, the SEES prototype system, with proper and up-to-date input from utilities' asset management systems and other inventory databases, could maintain a reference table of utility "presence" at locations, which can be of high accuracy and resolution, and include location identification based on an address range within a street representative of the underground asset locations. An example of records of the utility reference table includes the following relevant reference records for the work ticket described:

City, County, State, Street Name, Start Address, End Address, Zip Code, Utility Name, Utility Type:

Newark, Essex, NJ, Main Street, 2, 2100, 07102, Verizon, Communications
Newark, Essex, NJ, Main Street, 2, 1100, 07102, PSE&G, Power
Newark, Essex, NJ, Main Street, 2, 1300, 07102, PSE&G, Gas
Newark, Essex, NJ, Main Street, 2, 2100, 07102, Newark Water and Sewer, Water
Newark, Essex, NJ, Main Street, 2, 2100, 07102, Newark Water and Sewer, Sanitary Sewer
Newark, Essex, NJ, Main Street, 2, 2100, 07102, Newark Water and Sewer, Storm Sewer

Using the address range inferred from 1) a or 1) b or 1) c, the SEES prototype identifies utilities located in excavation area and sends e-mails to Verizon, PSE&G Power, PSE&G Gas, Newark Water and Sewer/Water, etc. to notify them of request for Mark-Out and transfers location/extent of excavation information as described in 1-a through 1-c above.

For the purposes of the prototype, a first "release" of the utility reference table at a street name level identification was built-into the utility reference table. Given the street name, city and state geographic location of the excavation job ticket, the list of utility owners from various infrastructure types (water, power, gas, sewer, communications, etc.) with assets at that geographic location would be derived by the system, and a complete communication of the Excavation Work Ticket record would be initiated via e-mail and exchange message notification. Each utility receiving the message would now have to communicate to SEES the set of assets in need for mark-out, in order to facilitate and improve the accuracy of the mark-out process vis-à-vis the excavation site area, and the scope and extent of the related work.

3- Asset Identification and Communication, Mark-Out Assignment:

Every Utility which receives the e-mail/request for mark-out as a result of Section 2 above, makes a search within the excavation area (+20 feet each way for safety) for assets located within the boundaries of the excavation area.
For example, Verizon might return from its automated asset management system (AMS) a list (Inventory) of 3 assets:

1- A Junction Box located at 980 Main Street, Newark, NJ
2- A Pipe/Fiber Optic Conduit extending from 980 Main Street to 1240 Main Street, Newark, NJ
3- A Junction Box Located at 1240 Main Street Newark, NJ

For the purposes of the mark-out process, it is assumed that only linear assets (pipes) are retained for location identification. Pipes elements are segments with a start node and an end node. In the SEES system, the coordinates, location address, the distance to curb, as well as an additional reference are allowed for both the start and the end nodes of a pipe segment.

Every concerned utility would then create an internal Mark-Out Work Scope, which includes the list of assets which fall within the excavation area, and the Assigned Mark-Out Professional, selected among a list of approved and registered mark-out professionals. One of the new features of the SEES open exchange system is the addition of the mark-out professional as a stakeholder in the mark-our process.

4- Asset Mark-Out for every Utility with Assets at the Excavation Area, Location Updating and and Communication:

The Mark-out Professional assigned by each utility uses the list of assets and locations as identified by the utility owner to perform his/her mark-out job. At the completion of the mark-out process, the SEES allows the mark-out professional to enter direct location coordinates or distances to reference points for each asset. SEES keeps track of the completion of each utility mark-out job required to complete the mark-out tasks for the excavation work ticket.

In future releases of the SEES, an improvement to the workflow can be made to allow multiple communications between the mark-out professional and the utility owner's engineering and asset management departments in order to obtain all relevant information about the utility assets, including engineering and as-built drawings, as well as location of assets as found in the utility asset inventory management or GIS system.

Downstream To Be Process Flow:

1- Asset Mark-Out for every Utility with Assets at the Excavation Area, Location Updating and and Communication:

Once all the mark-outs of all utilities with assets located at the excavation site, have been completed, the SEES system would flag the excavation work ticket as ready for commencement of excavation work. Consequently, the Excavator is allowed the opportunity to enter after completing the excavation, for each utility identified during the excavation process the "actual" coordinates as measured, or related distance to known references.

2- Asset Location Investigation in case of Conflict between Mark-Out and Post-Excavation coordinates:

If the coordinates or distance referencing of various assets located in the excavation area differ significantly (usually more than 2 feet of variance), then an Investigator can be called upon to verify the exact location of the assets. The outcome of this investigation can be saved in a set of coordinates or geographic references considered as the last and final arbitrated and determined locations.

Following the creation of these Investigator generated asset coordinates, the Utility Owners are afforded the opportunity to update their utility systems databases of asset location data in order to help improve the location information accuracy over time, and minimize the risk of accidents from mis-located assets.

It is worth noting that the role of the Investigator was included under the set of tasks handled by the system administrator, in order to preserve data integrity without creating another category of User.

It is worth noting that the data related to asset location (direct coordinates or v/s reference points) for the 3 stages of asset identification (UTILITY/MARK-OUT/EXCAVATOR) is stored in a staging area related to the work ticket. Once the outcome of the workflow is determined, and utility asset coordinates are updated as a result of communication of final coordinates or distances to reference points back to the concerned utility for internal processing, the asset locations are archived in an area that only individual asset owners can access with their own passwords in order to keep location information secure.

The design of the SEES prototype system ensures that it does not become a large mega-geodetic database or centralized repository containing all location information for all utilities. This feature guarantees the security and integrity of location information resulting from the one-call process and the SEES system. In summary, the central EXCHANGE system would not store the location information (whether direct or v/s reference points) because each utility needs to keep its asset location information private for security information, and would allow such asset location information to be provided only during the one-call process cycle, so location information accuracy can be improved over time.

The sequence diagram associated with the To-Be workflow is shown in Figure 9.

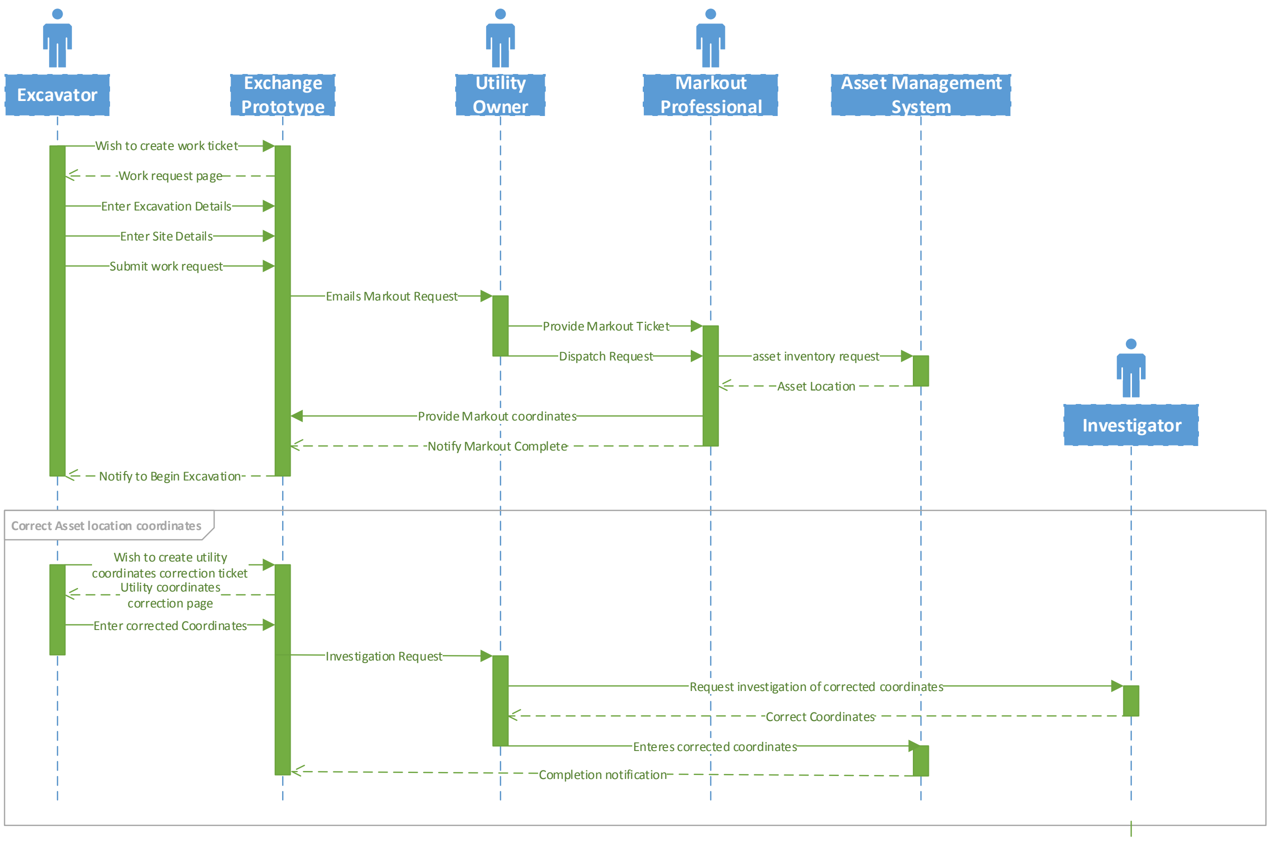

Figure 9. Safe Excavation Exchange System Prototype Sequence Diagram

3.3. SEES Entity Relationship Diagram, SEES Data Model

The SEES Entity relationship Diagram and data model are shown in Figure 10 and the data structure definitions described next.

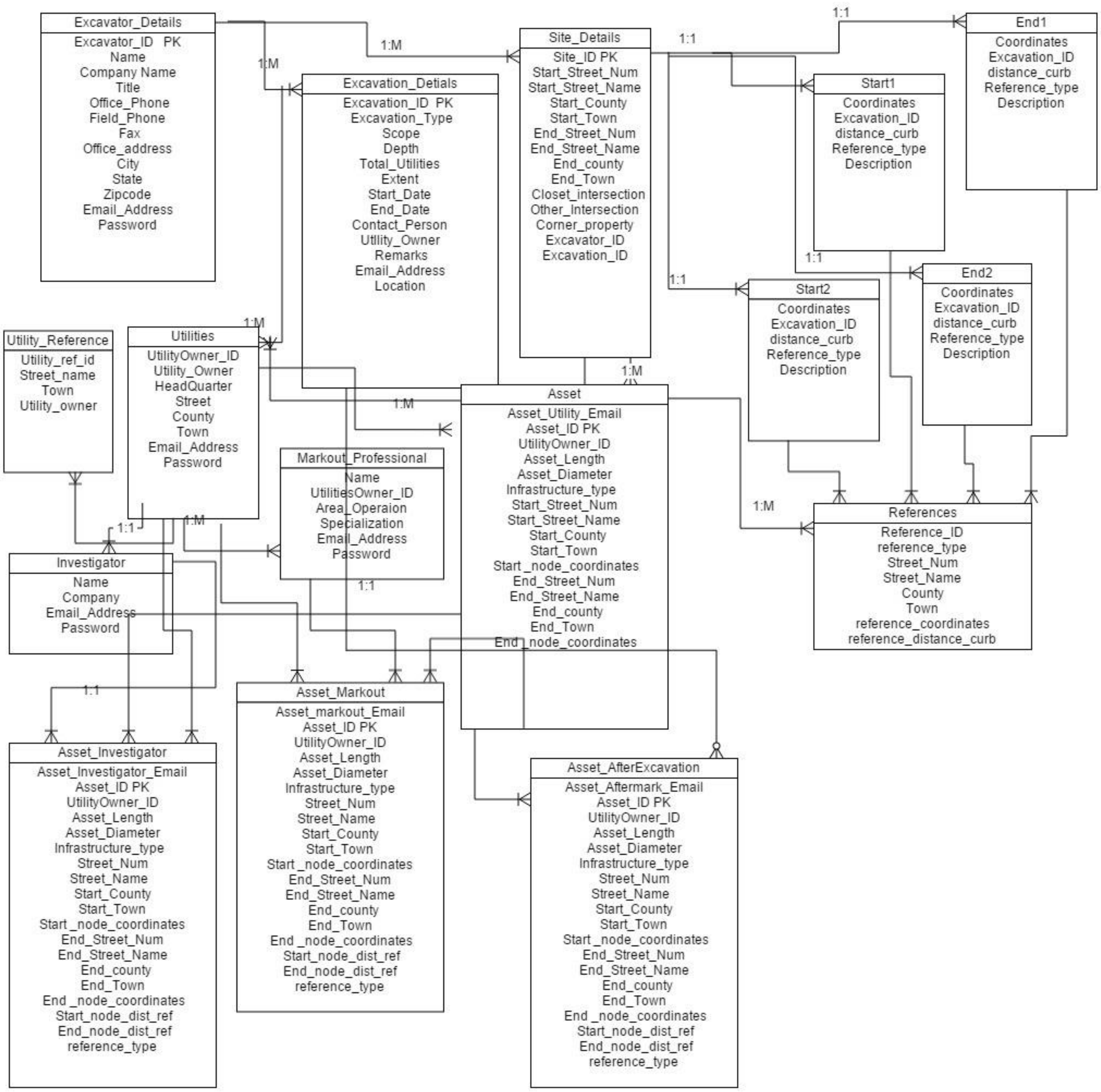

Figure 10. Entity Relationship Diagram and Data Model

Field Description:

Excavator_Details

1. Excavator_Id : This is a unique Id that each excavator is assigned when he logs in to the system to create a User account. Every User account is password protected.
2. Name: Name of the Excavator.
3. Company: This field specifies the company the excavator is working for.
4. Title: This field requires the excavator to give his title at the company he is working for.
5. Office Phone: This Field requires the office phone number of the excavator.
6. Field Phone: This Field requires the field phone number of the excavator.
7. Fax: This Field requires the Fax number of the excavator.
8. Contact_person: This field requires entering the person responsible for the excavation to be carried.
9. Office Address: This field requires the excavator to enter his office address for the company he is working.
10. City: City of the excavator’s office location.
11. State: State of the excavator’s office location.
12. Zip code : State of the excavator’s office location.
13. Email Address: Email address of the excavator.

Excavation_Details

1. Excavation_Id : This is a unique id to identify each excavation.
2. Excavation_type: This field requires selecting whether it is an emergency excavation or regular excavation.
3. Scope: The scope of the excavation work field , e.g. installation of new electric service, water main replacement, etc.
4. Depth: This field requires mentioning the depth of the excavation to be performed.
5. Total Utilities: This field requires the total number of utilities present at the given location site.
6. Extent: This field requires entering the extent of work, such as curb to curb etc.
7. Start Date: Specifies the start date of excavation.
8. End Date: Specifies the End date of excavation.
9. Contact_person: This field requires entering the person responsible for the excavation to be carried.
10. Utility_owner: The field requires specifying the name of the utility whose asset is present at the excavation site.
11. Remark: This field contains any special information to be conveyed to the actual markout professional.
12. Email Address: Email address of the contact person.

Site_ Details

1. Site Id: This is a unique id to identify each exaction site.
2. Start Street number: It is the approximate street number at the start of the site where excavation needs to be performed.

3. Start Street name: It is the street name at the start of the site where excavation needs to be performed.
4. Start County: It is the name of the county at the start of the site where the excavation needs to be performed.
5. Start Town: It is the name of the town at the start of the site where the excavation needs to be performed.
6. End Street number: It is the street number at the end of the site where the excavation needs to be performed.
7. End Street name: It is the street name at the end of the site where the excavation needs to be performed.
8. End County: It is the name of the county at the end of the site where the excavation needs to be performed.
9. End Town: It is the name of the town at the end of the site where the excavation needs to be performed.
10. Closest Intersection: This field specifies the closest intersection to the area of the excavation.
11. Other intersection: This field specifies intersection points other than those close to site of excavation
12. Corner property: The field requires to mention corner property if present near the site of excavation.

Start1

1. Coordinates: This field requires entry of the coordinates for the first or Northern start point of the excavation site.
2. Distance Curb: This field requires entering the distance of any nearby curb for the first or Northern start point of the excavation site.
3. Reference_type: This field requires entering the type of reference (pole, tree, manhole etc) nearby the northern starting point at the excavation site.
4. Description: This field requires entering any special remarks.

Start2

1. Coordinates: This field requires entry of the coordinates for the second or Southern start point of the excavation site.
2. Distance Curb: This field requires entering the distance of any nearby curb for the first or Southern start point of the excavation site.
3. Reference_type: This field requires entering the type of reference (pole, tree, manhole etc) nearby the southern starting point at the excavation site.
4. Description: This field requires entering any special remarks.

End1

1. Coordinates: This field requires entry of the coordinates for the first or Northern end point of the excavation site.
2. Distance Curb: This field requires entering the distance of any nearby curb for the first or Northern end point of the excavation site.

3. Reference_type: This field requires entering the type of reference (pole, tree, manhole etc) nearby the northern ending point at the excavation site.
4. Description: This field requires entering any special remarks.

End2

1. Coordinates: This field requires entry of the coordinates for the second or Southern end point of the excavation site.
2. Distance Curb: This field requires entering the distance of any nearby curb for the first or Northern start point of the excavation site.
3. Reference_type: This field requires entering the type of reference (pole, tree, manhole etc) nearby the southern ending point at the excavation site.
4. Description: This field requires entering any special remarks.

Utilities

1. Utility Owner Id: This is a unique Id that each utility owner will be assigned when he logs in to the system. The utility owner will log in with this ID and his password.
2. Utility Owner : This is the name of the utility owner
3. Headquarter: This field requires to mention the location name of the utility headquarter office
4. Street: City of the utilities office location.
5. Town: State of the utilities office location.
6. County: County of the utilities office location.
7. Email Address: Email address of the excavator.
8. Password: This field specifies the password of the Utility owner account.

References

1. Reference Id : This is a unique Id that each reference (curb, pole, tree, etc.) will have.
2. Reference_type: This field requires to enter the type of reference (pole, tree, manhole etc) nearby the excavation site.
3. Street number: It is the Street number of the site where the reference is located.
4. Street: City of the reference location.
5. Town: State of the reference location.
6. County: County of the reference location.
7. Reference_coordinates: This field requires entering the coordinates of the reference point.
8. Reference distance to curb: This field requires entering distance of reference from the curve.

Markout Professional

1. Name: Name of the mark out professional.
2. Utility Owner Id: This field is used to identify the utility owner that the mark out professional works for on a particular work ticket.
3. Area of Operation: This field is used to identify the area of operation of the mark out professional.

4. Specialization: This field specifies the expertise of the mark out professional.
5. Email Address: Email address of the mark out professional.
6. Password: This field specifies the password of the mark out professional.

Investigator

1. Name: Name of the investigator.
2. Company: This field specifies the name of the company the investigator works for.
3. Email Address: Email address of the investigator.
4. Password: This field specifies the password of the investigator.

Utility_Reference

1. Utility_Ref_id: This field is the key of the table. It is used to identify the references. This table is basically like a repository containing all the references.
2. Street Name: This field specifies a street name for a given location
3. Town: This field specifies a Town for a given location
4. Utility_Owner: This field specifies a utility owner with pipes at that street/town location.

Asset

1. Asset_Utility_Email: This field is used to identify asset location from the utility owners.
2. Asset_ Id : This field is is used to identify the assets.
3. UtilityOwner_Id: This field is used to identify the Utility Owner for the current asset.
4. Asset_ length: This field is used to specify the length of the asset (ex. pipe length).
5. Asset_Diameter: This field is used to specify the diameter of the asset (ex. pipe diameter).
6. Infrastructure Type: This field specifies whether it is a gas line, water line etc.
7. Start Street number: It is the street number of the site where the asset starts.
8. Start Street name: It is the street name of the site where the asset starts.
9. Start County: It is the name of the county where the asset starts.
10. Start Town: It is the name of the town where the asset starts.
11. End Street number: It is the street number of the site where the asset ends.
12. End Street name: It is the street name of the site where the asset ends.
13. End County: It is the name of the county where the asset ends.
14. End Town: It is the name of the town where the asset ends.
15. Start_node_Coordinates: This field contains the starting coordinates of the asset.
16. End_node_Coordinates: This field contains the ending coordinates of the asset.

Asset_ Markout

1. Asset_Utility_Email: This field is used to identify asset location from mark-out professionals.
2. Asset_Id : This field is is used to identify the assets.
3. UtilityOwner_Id: This field is used to identify the Utility Owner for the current asset.
4. Asset_ length: This field is used to specify the length of the asset (ex. pipe length).
5. Asset_ Diameter: This field is used to specify the diameter of the asset (ex. pipe diameter).

6. Infrastructure Type: This field specifies whether it is a gas line, water line etc.
7. Start Street number: It is the street number of the site where the asset is present.
8. Start Street name: It is the street name of the site where the asset starts.
9. Start County: It is the name of the county where the asset starts.
10. Start Town: It is the name of the town where the asset starts.
11. End Street number: It is the street number of the site where the asset ends.
12. End Street name: It is the street name of the site where the asset ends.
13. End County: It is the name of the county the asset ends.
14. End Town: It is the name of the town where the asset ends.
15. Start_node_Coordinates: This field contains the starting coordinates of the asset.
16. End_node_Coordinates: This field contains the ending coordinates of the asset.

Asset_Investigator

1. Asset_Investigator_Email: This field is used to identify asset location by Investigators.
2. Asset_ Id: This field is is used to identify the assets.
3. UtilityOwner_Id: This field is used to identify the Utility Owner for the current asset.
4. Asset_ length: This field is used to specify the length of the asset (ex. pipe length).
5. Asset_ Diameter: This field is used to specify the diameter of the asset (ex. pipe diameter).
6. Infrastructure Type: This field specifies whether it is a gas line, water line etc.
7. Start Street number: It is the street number of the site where the asset starts.
8. Start Street name: It is the street name of the site where the asset starts.
9. Start County: It is the name of the county where the asset starts
10. Start Town: It is the name of the town where the asset starts.
11. End Street number: It is the street number of the site where the asset ends.
12. End Street name: It is the street name of the site where the asset ends.
13. End County: It is the name of the county the asset ends.
14. End Town: It is the name of the town where the asset ends.
15. Start_node_Coordinates: This field contains the starting coordinates of the asset.
16. End_node_Coordinates: This field contains the ending coordinates of the asset.

Asset_Afterexcavation

1. Asset_Excavator_Email: This field is used to identify asset location by Excavators.
2. Asset_ Id: This field is used to identify the assets.
3. UtilityOwner_Id: This field is used to identify the Utility Owner for the current asset.
4. Asset_ length: This field is used to specify the length of the asset (ex. pipe length).
5. Asset_ Diameter: This field is used to specify the diameter of the asset (ex. pipe diameter).
6. Infrastructure Type: This field specifies whether it is a gas line, water line etc.
7. Start Street number: It is the street number of the site where the asset starts.
8. Start Street name: It is the street name of the site where the asset starts.
9. Start County: It is the name of the county where the asset starts.
10. Start Town: It is the name of the town where the asset starts.
11. End Street number: It is the street number of the site where the asset ends.

12. End Street name: It is the street name of the site where the asset ends.
13. End County: It is the name of the county the asset ends.
14. End Town: It is the name of the town where the asset ends.
15. Start_node_Coordinates: This field contains the starting coordinates of the asset.
16. End_node_Coordinates: This field contains the ending coordinates of the asset.

4. SYSTEM ARCHITECTURE AND DEVELOPMENT OF SYSTEM INTERFACES

4.1. System Hardware Architecture

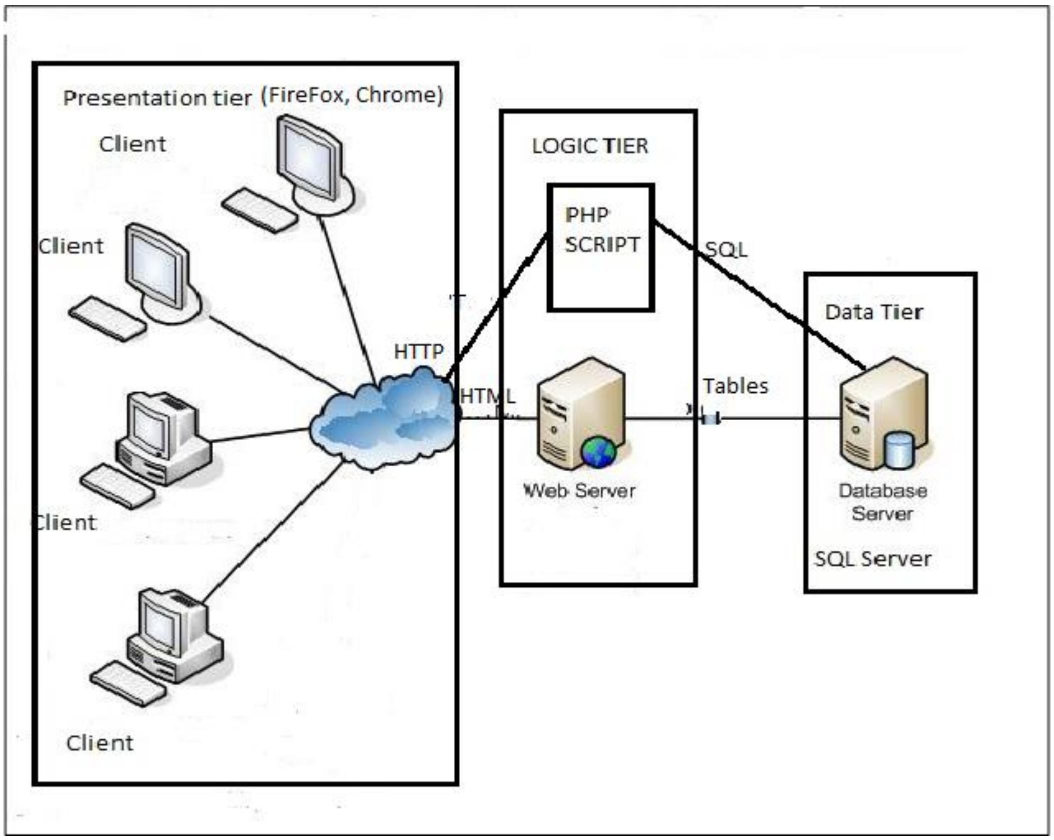

Figure 11. Representation of the SEES Multi-Tiered Systems Architecture

The system hardware should be capable of running a web server and a database server. The client interface can be accessed from a PC-based browser as well as a cellular phone.

4.2. System Software Architecture

Web Server Configurations:

Apache- MySQL
Server: fdb4.biz.nf via TCP/IP

Server version: 5.5.38-log
Protocol version: 10
User: 1932453_safe@82.197.130.17
MySQL charset: UTF-8 Unicode (utf8)

Web server Configurations:

The various software components include
PHP - v5.4.42
MySQL - v5.5
HTML - v5.0
Bootstrap - v3.3.5
JQuery - v1.11.3
Web Browser (Cookies Enabled)

The database is a relational database model. Tables are linked based on the relation with each other. Foreign keys and primary keys are accesses accordingly. Logical representation of the database is shown in the ERD above.

Tables:

Excavator_Details
Excavation_Details
Site_Details
Start1
Start2
End1
End2
Asset
Asset_Afterexcavation
Asset_Investigator
Asset_Markout
Markout_professional
Investigator
Utility_Reference
References1
Utilities

4.3. SEES Root Screen, User Creation and Upstream Work Interfaces

The SEES root screen shown in Figure 12 provides the same entry into the excavation exchange system for all users account creation or log-in. The primary users are the Excavator (Excavation Contractor or party performing excavation work on behalf of utility owner), who creates the Work Ticket and defines the work scope and excavation area, as determined in the contract or emergency work order. The Utility owners and operators are members of the exchange system and interface with the system to provide asset referencing information for general identification, as well as initial asset location information in support of the mark-out process. The mark-out professionals are typically working for the utility owners or are part of the utility owner organization. The System Administrator manages the back-end processes, including the geographic referencing system for utility maps at the street level, and provides the administrative interface for the resolution of potential asset location conflicts between the Mark-out professional and the Excavator through the role of Investigator, which is embedded into the functionality of the System Administrator.

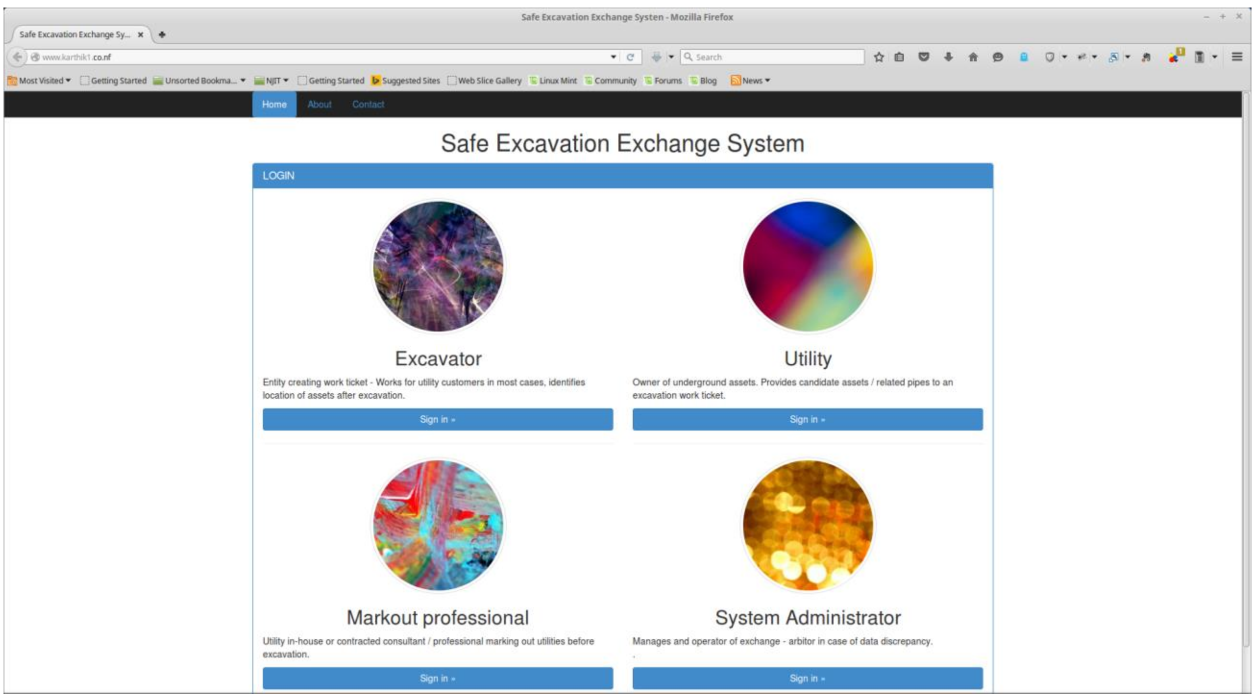

Figure 12. Master SEES Root Screen for All User Creation and Login

4.4. Excavator High-Level Workflow: Pre-Excavation Stage and Post-Excavation

After accessing his/her account, the Excavator has 3 major options displayed in Figure 13. Firstly, he can initiate the excavation request for mark-out, by creating an excavation work ticket, which launches the process of request for mark-outs from all concerned utilities.

The second key component of the Excavator workflow pre-excavation is the review of work tickets with completed Mark-outs, which is a pre-cursor to the start of excavation.

In the post-excavation stage, the Excavator is able to update the coordinates of the utility assets by providing a post-excavation digital mark-out of the assets and entering the updated mark-out coordinates in the SEES.

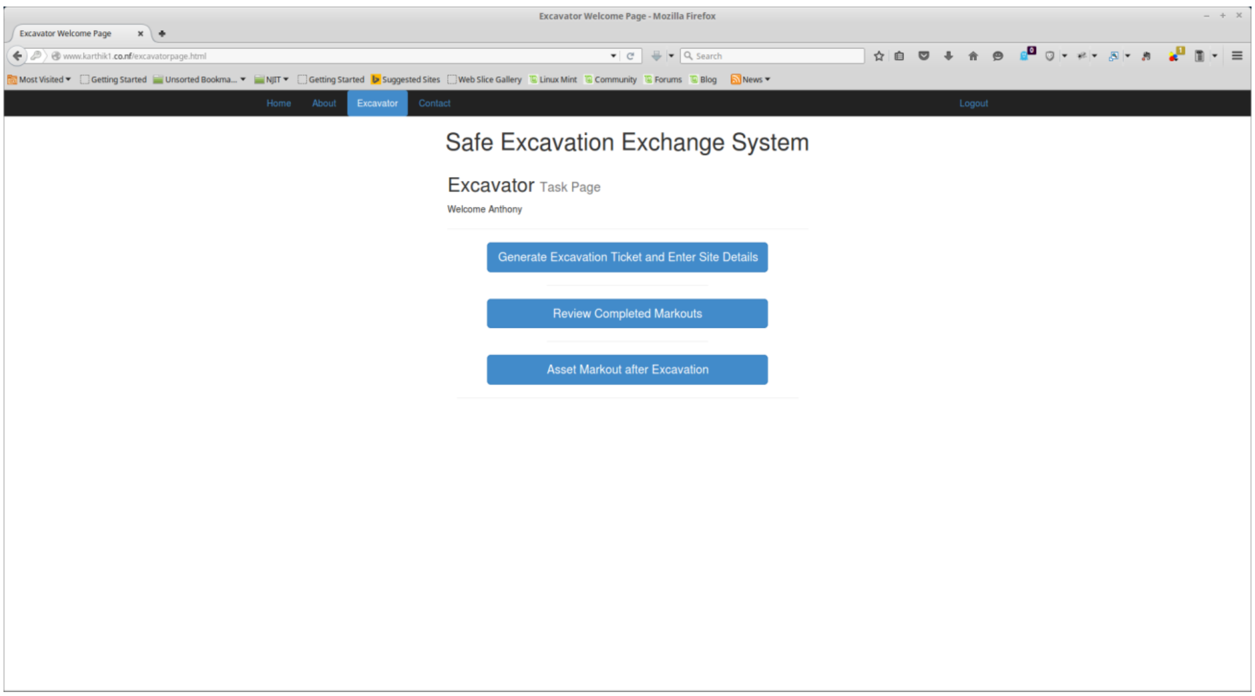

Figure 13. Excavator Workflow Options

4.5. Excavator Work Ticket Creation and Excavation Area Definition

The Excavator initiates the workflow process by creating a work ticket, defining the parameters of the work to be performed and the time frame for the performance of the mark-outs. The Excavator can initiate a Work request for mark-out performance on an emergency basis, or as a regular or routine request for excavation. The scope of the work, depth of excavation, possible total number of utilities with assets in place at the excavation site, the start and end date of the mark-out work, are all specified providing a little more specificity to the information currently provided via email to the utility owners with assets at the excavation site. The contact person at the Utility owner on whose behalf the work is being performed (e.g. gas pipe work, water main replacement, etc.), and the Utility owner are identified for the work request (Figure 14).

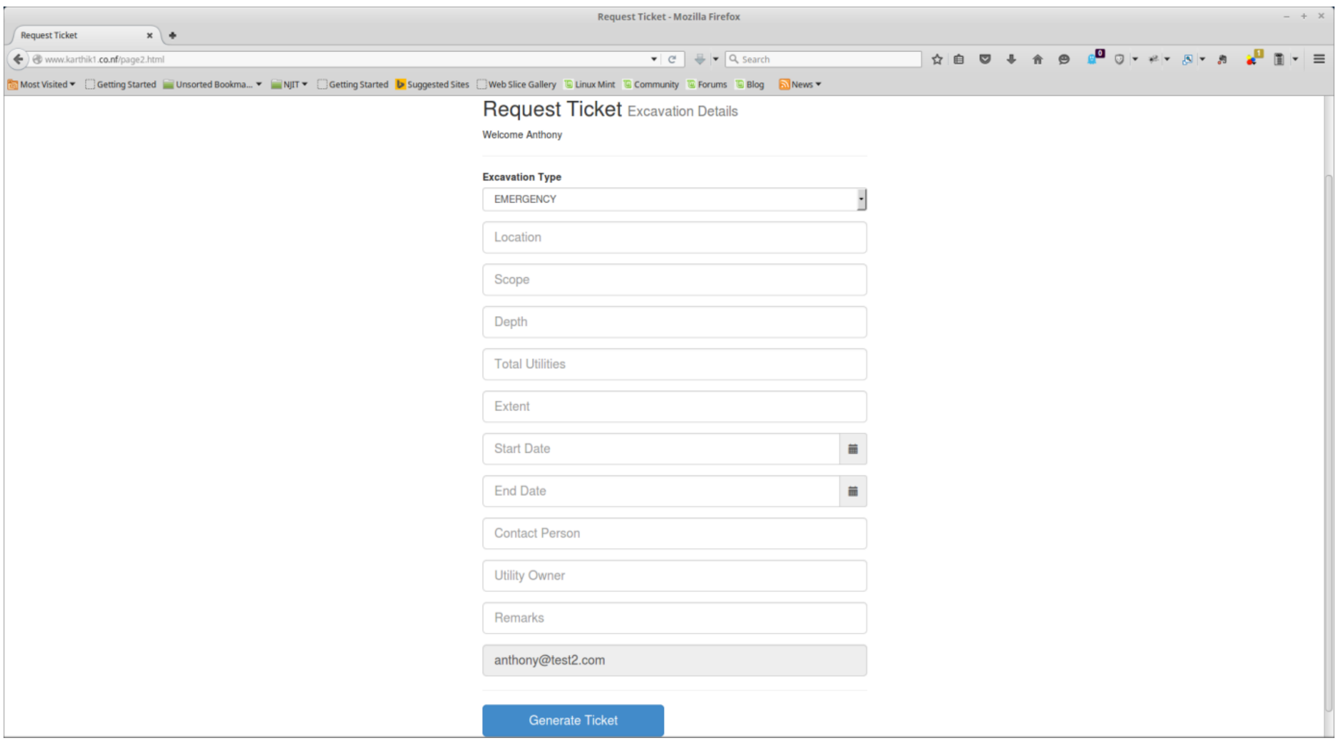

Figure 14. Excavator generating Excavation Ticket and Work Scope

The generation of the ticket follows the work ticket definition shown in Figure 14, and a more detailed Site specification enables the excavator to be more precise relative to the excavation area. The site details can then be entered by providing the closest start and end property/street address along a street or roadway for the excavation site, but also enable the entry of the four corner nodes of the excavation site, Start1, Start2, End1 and End2. These coordinates can then be integrated through an Automated Programming Interface into a mapping capability such as Google Map, thus enabling the sharing of the excavation area in a graphic mode. The entry screen for the site details is shown in Figure 15.

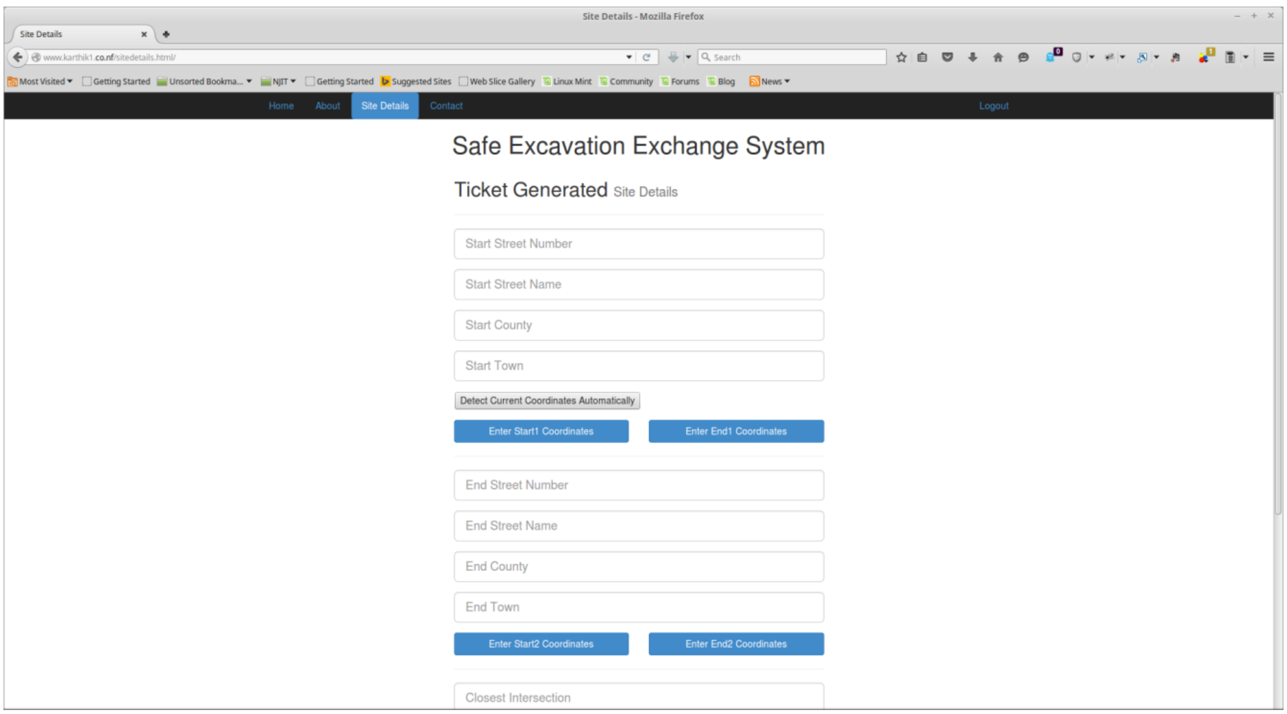

Figure 15. Excavator entering site details after creating Excavation Ticket

4.6. Utility Owner Automated Notification Work Ticket and Mark-Out Request

The SEES system, using its automated utility reference table, generates the list of utility owners with assets at the excavation site street location. The utility owner names are listed with a checked box next to each utility name to enable possible removal of the utility owner name in case of error in the reference table. This precedes the system initiation of emails to various utility owners with assets at the excavation site (Figure 16).

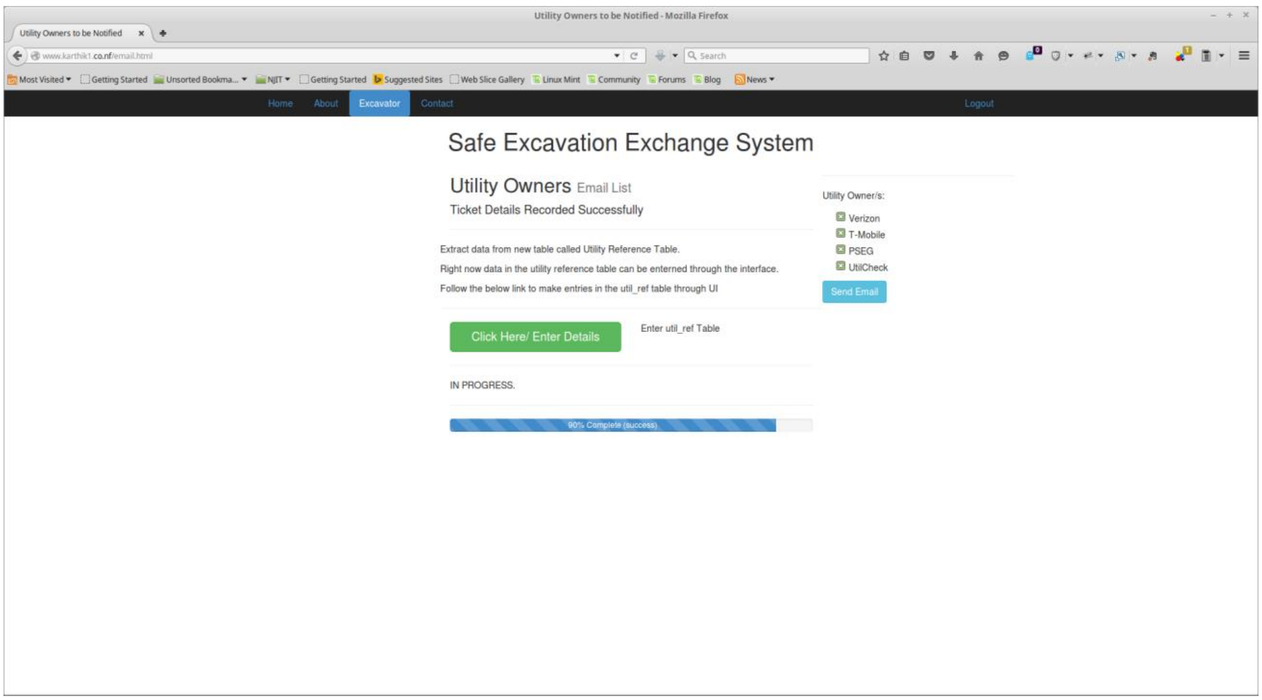

Figure 16. SEES generating messaging (emails) to Utilities with Assets in Excavation Area

4.7. Utility Owner Master Screen for Work Ticket Response Tasks: Mark-out Assignment and Asset Definition

As various Excavators enter Work Ticket requests for Mark-out upstream of the excavation work, an individual utility owner with assets located in the excavation area, will upon logging into the SEES exchange "see" the relevant work tickets that are pending for further action. A hypothetical utility owner "Utilquest1" screen is shown in Figure 17, with 2 work tickets in need for Markout Assignment (assignment of mark-out work to a specific "Markout Professional". Also, the system provides a capability for the utility owner engineering or asset management departments to add Assets (pipes) at the location of the excavation work.

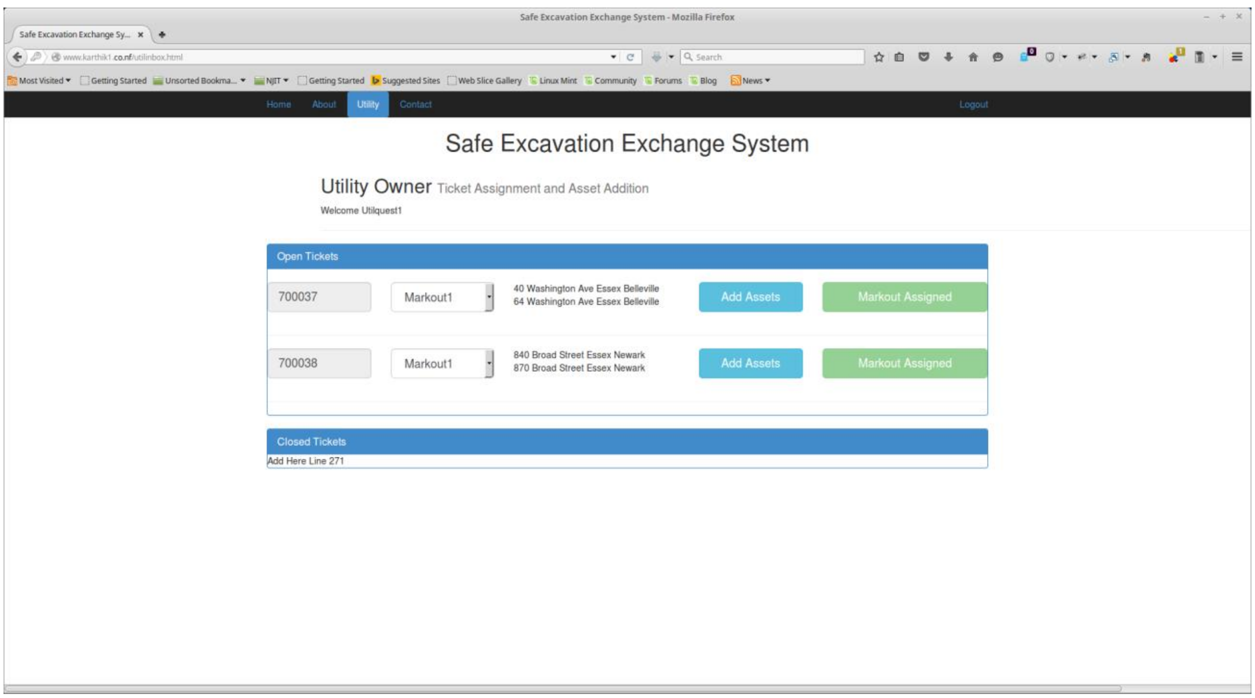

Figure 17. Utility Owner Summary Screen for Markout Assignment and Asset Additions

4.8. Markout Professional Upstream Interaction with SEES: Viewing Assigned Work Tickets and Entry of Post-Markout Coordinates

The Markout Professional (MP) is a User and member of the SEES; after logging into the exchange (Figure 18), he/she are able to view assigned work tickets by various utility customers who have assigned the markout of their utilities at the particular location of the work ticket(s). Hypothetically, a markout professional can be assigned to the same work ticket multiple times, by various client utilities in order to undertake the mark-out of their pipe assets.

After logging in, the MP is able to see the view the work tickets (Figure 19) assigned to him/her and proceed to review the Assets to be marked out. The asset coordinates and locations as identified by the utility owners are given as a starting point to the MP.

After performing the markout task, the MP can update the coordinates and addresses of the key starting and ending nodes of various pipe segments assigned to the MP and located in the excavation area related to the work ticket (Figure 20).

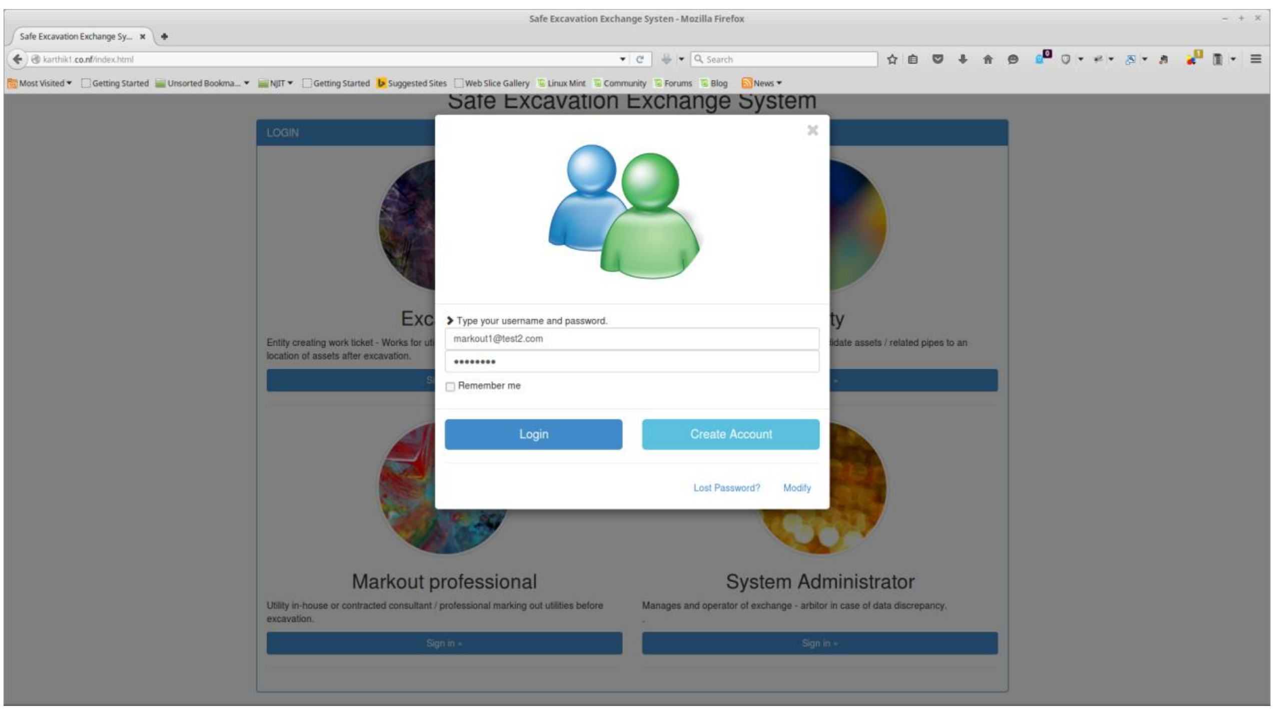

Figure 18. Mark-out professional (one of the 4 key quadrant users) logging into the SEES

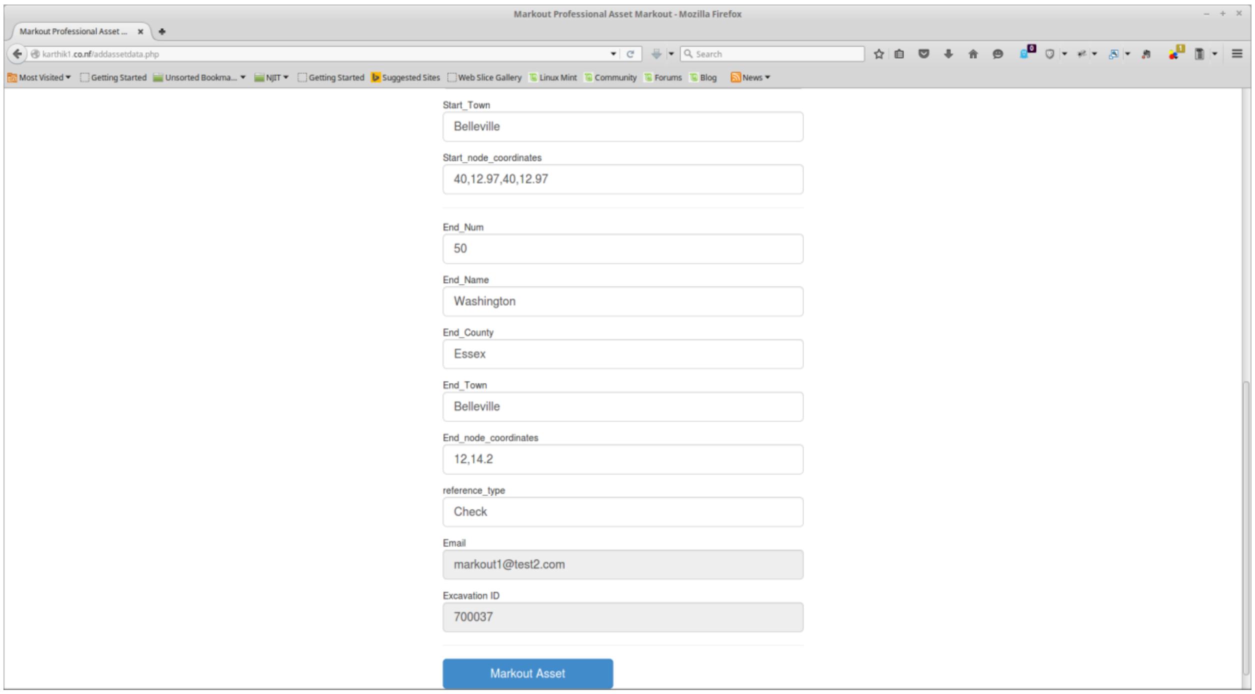

Figure 19. Mark-out professional viewing assigned work ticket

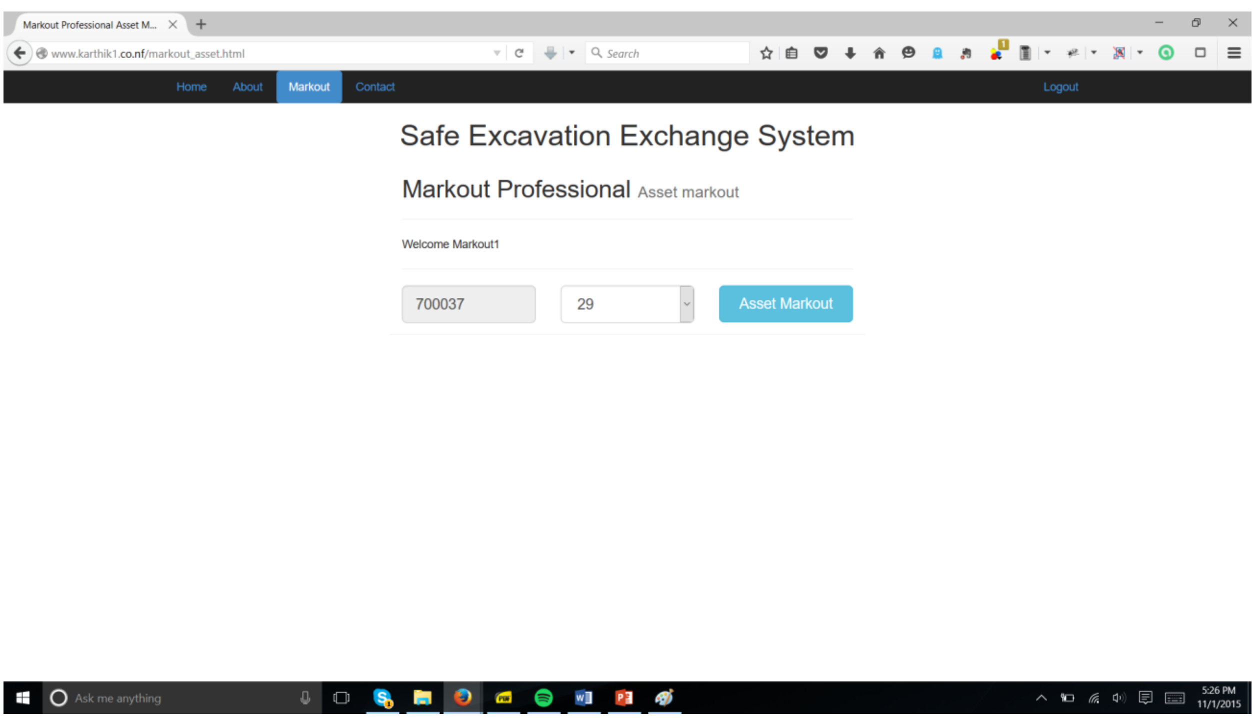

Figure 20. Mark-out professional updating location coordinates and information of pipe segment

4.9. Excavator Review of Work Ticket Completion and Downstream Entry of Pipe coordinates

The excavator has the option to view the progress of the mark-out tasks to make sure all utilities with assets at the excavation site(s) have had their mark-out completed. Progress of the mark-out tasks on a work ticket basis can be shown in Figure 21.

For tickets which mark-out is completed across all utilities, the Excavator can proceed to perform the excavation Work. For such work tickets, the ability to now enter the coordinates of the pipes is now open to the excavator (figure 22).

On any completed work ticket, the Excavator can enter the coordinates of the start and end nodes of the pipe segments (Figure 23), which are now available for comparison with the coordinates entered by the Utility owners and the mark-out professionals.

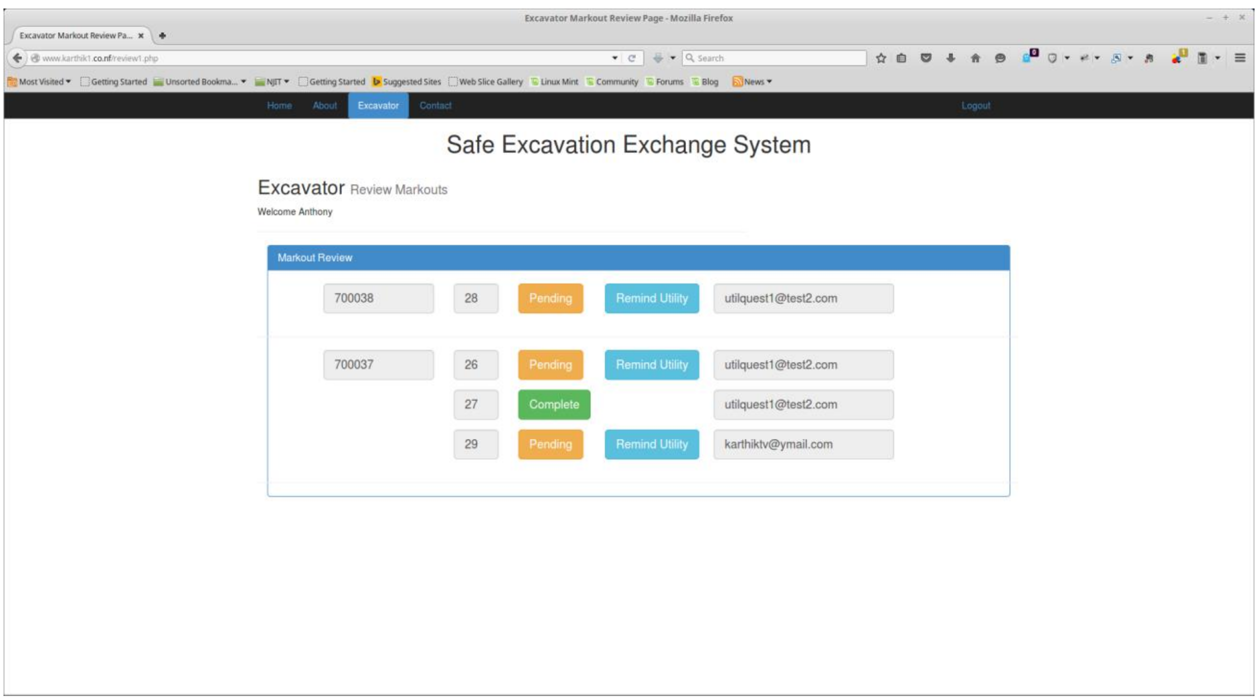

Figure 21. Progress of Mark-out work on behalf of Utility Owners (Pending v/s Complete)

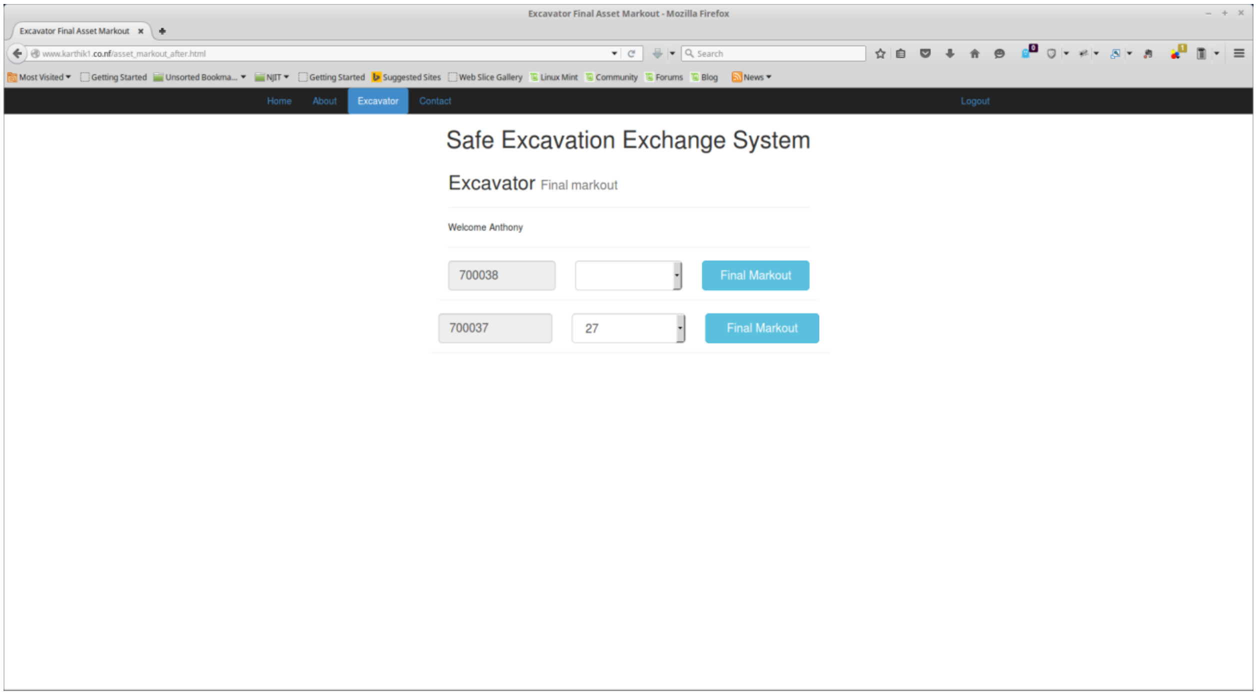

Figure 22. Excavator proceeding to entry of pipe coordinates after excavation (downstream)

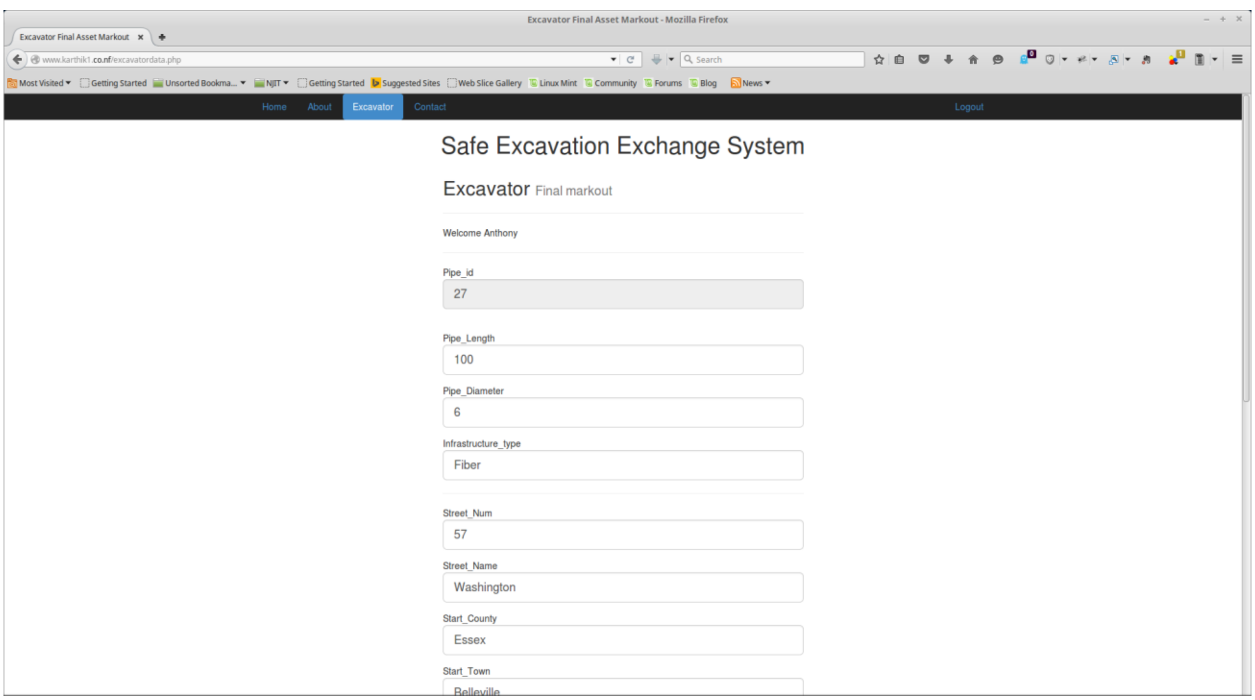

Figure 23. Excavator updating individual pipe coordinates after excavation (downstream)

4.10. Key Roles of the System Administrator: Maintenance of Utility Reference table, Reference Asset Maintenance and Post-Excavation Location Investigator

The System Administrator occupies the fourth quadrant of the Exchange master screen and is a key user. The key roles of the administrator are:

1- To oversee and maintain the utility reference table, which includes the identification by street name and city of utility with asset presence underground (figure 24)
2- To oversee the data entry and maintenance of the above-ground reference assets (figure 25). This function is also allowed for utility owners in a self-entry mode (figure 26)
3- To enter the asset coordinates for asset with location information conflicts between the excavator and the mark-out professional and/or the utility, in order the determine the final and accurate location coordinates resulting from the intervention of an Investigator.

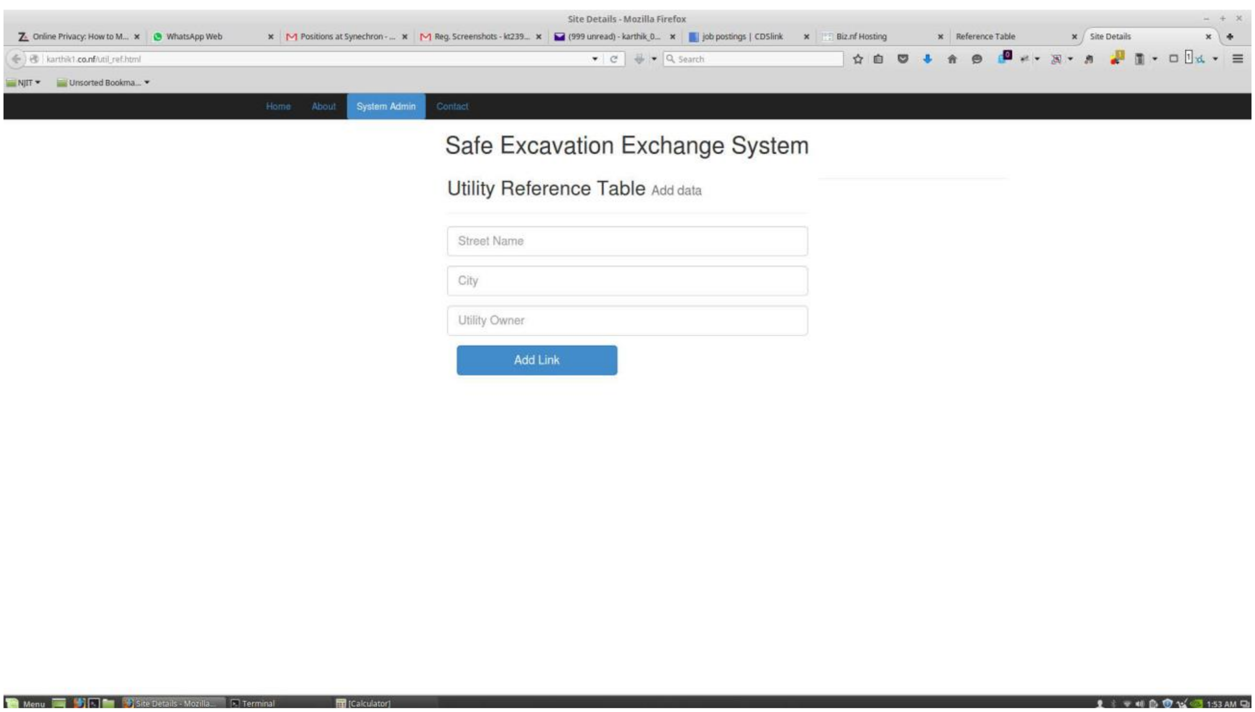

Figure 24. System Administrator Maintenance Function for Utility Reference Table

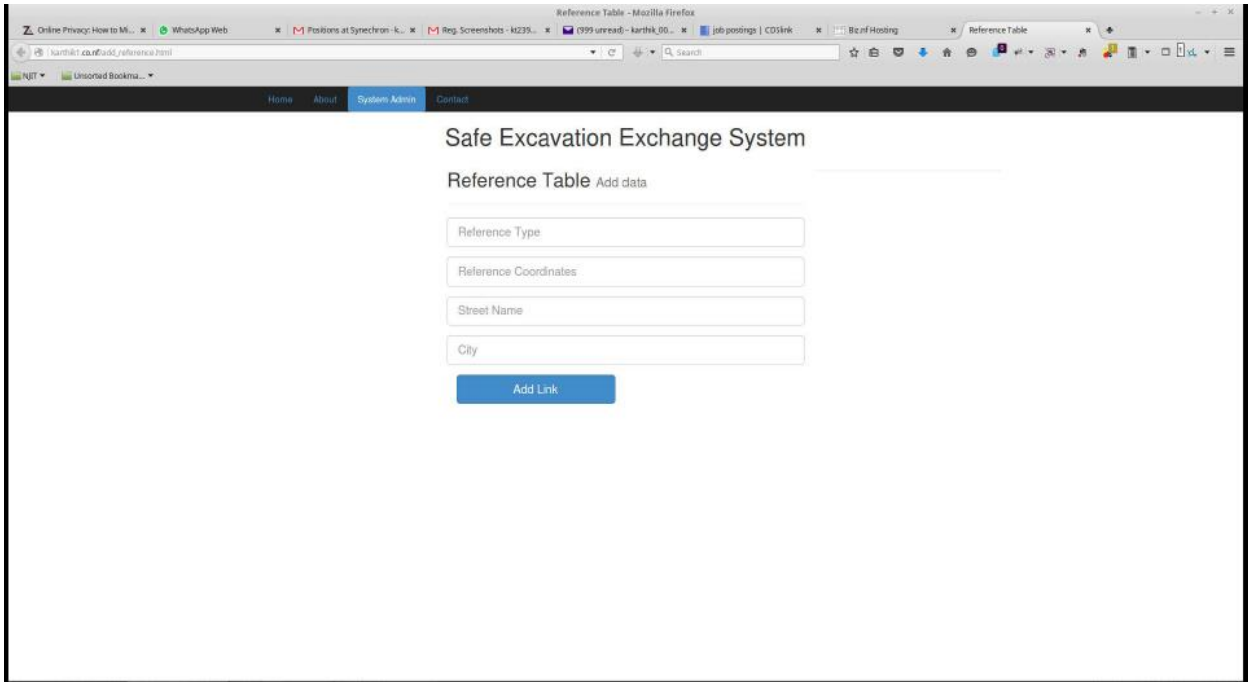

Figure 25. System Administrator function of reference asset data entry and maintenance

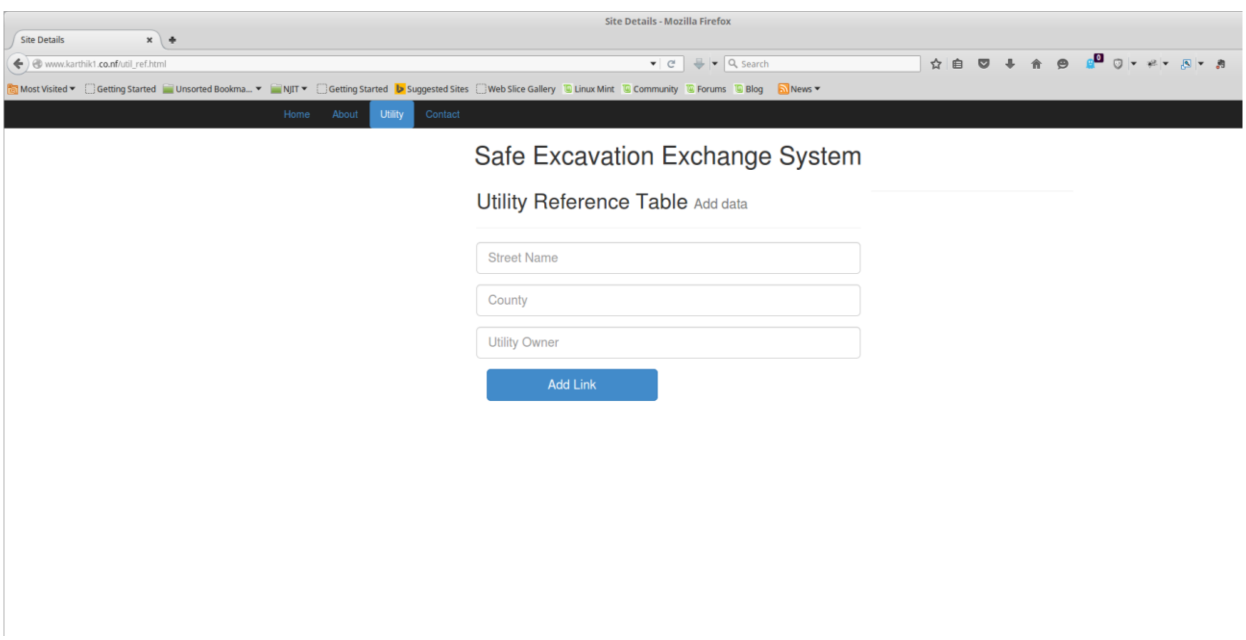

Figure 26. Option of utility reference table data entry in a self-entry mode

5. SUMMARY AND CONCLUSIONS

In this work, an exchange prototype was designed and developed as a model for creating an information platform for the key constituents to interact during the pre-excavation stage also called the Upstream process, and in the post-excavation stage also called the Downstream process.

Unlike the current system where the system interaction is primarily between the excavator and the system administrator, the proposed Safe Excavation Exchange System opens up the Upstream and Downstream processes to Excavators, Utility Owners, Mark-out Professionals or subsurface utility engineers, as well as the system administrator. The automation of many of the key components of the safe excavation timeline enables a number of best practices. In particular, the improvement of location information is ensured through the systematic documentation and comparison of the location of underground assets as determined initially from the utility asset management system, then through the performance of asset mark-outs in the Upstream process, and subsequently from the excavator location determination in the Downstream process. When major discrepancies or conflicts between such location sets arise, an Investigator role is included within the System Administrator role, thus leading to a final resolution of location information before the work ticket is “closed”.

Other key benefits include the ability for an excavator to view the progress of the mark-out work in order to effectively plan the start of excavation, or deal with any possible contingencies due to potential delays in mark-outs. The creation of a Utility reference table enables an accurate definition of utilities with assets at any given street/city combination, reducing significantly the number of messages sent to utilities for work to be performed in areas where they may not have pipes underground.

While the system provides a blueprint for a model safe excavation exchange, it is envisioned that further extensions in the areas of visualization and analytics can improve the likelihood of voluntary adoption by all parties. Also, its implementation in concert with agencies responsible for transportation assets or public utilities would require further customization to adapt it to the specific regulations in place.

6. REFERENCES

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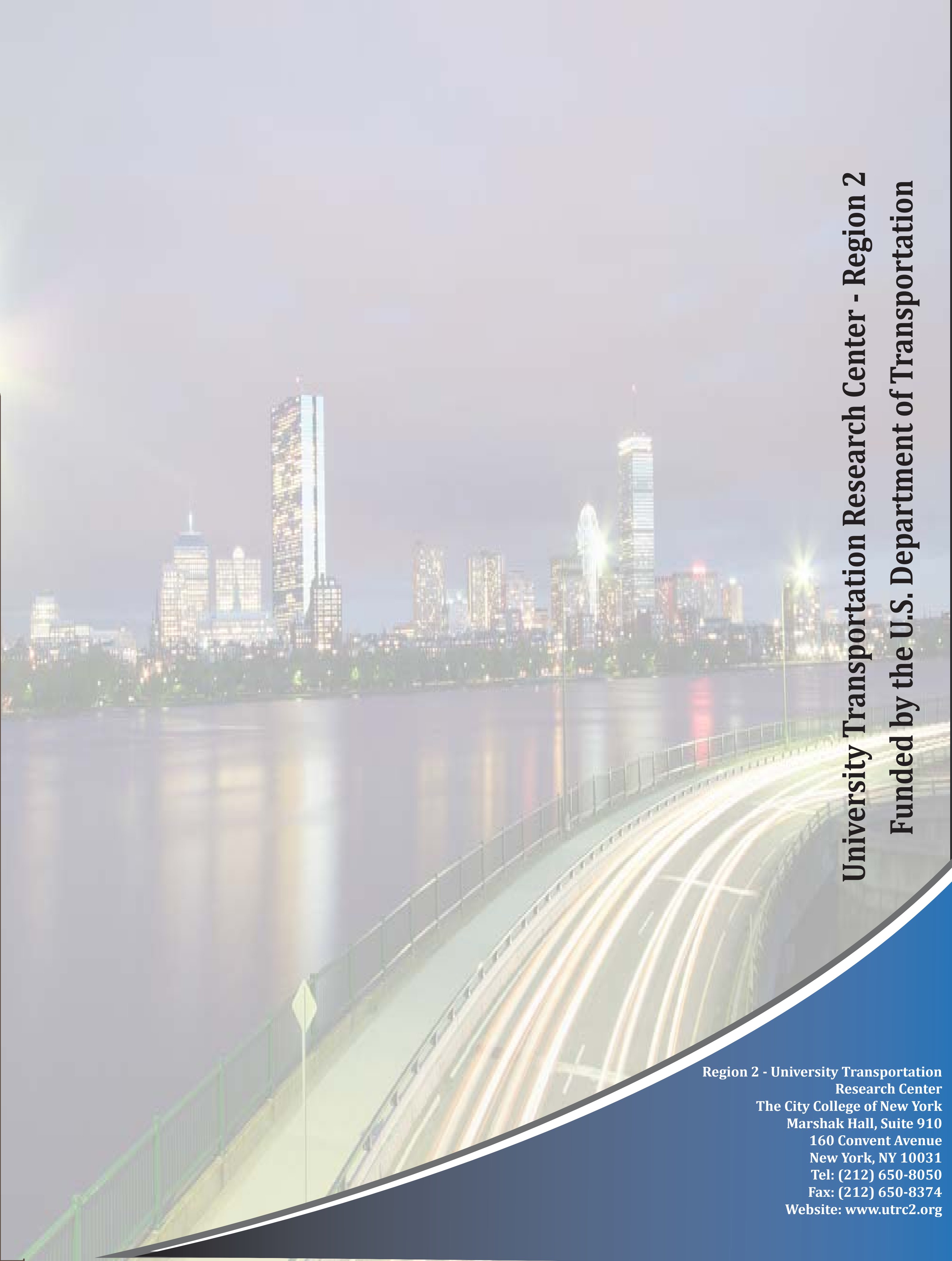

University Transportation Research Center - Region 2
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Region 2 - University Transportation Research Center
The City College of New York
Marshak Hall, Suite 910
160 Convent Avenue
New York, NY 10031
Tel: (212) 650-8050
Fax: (212) 650-8374
Website: www.utrc2.org