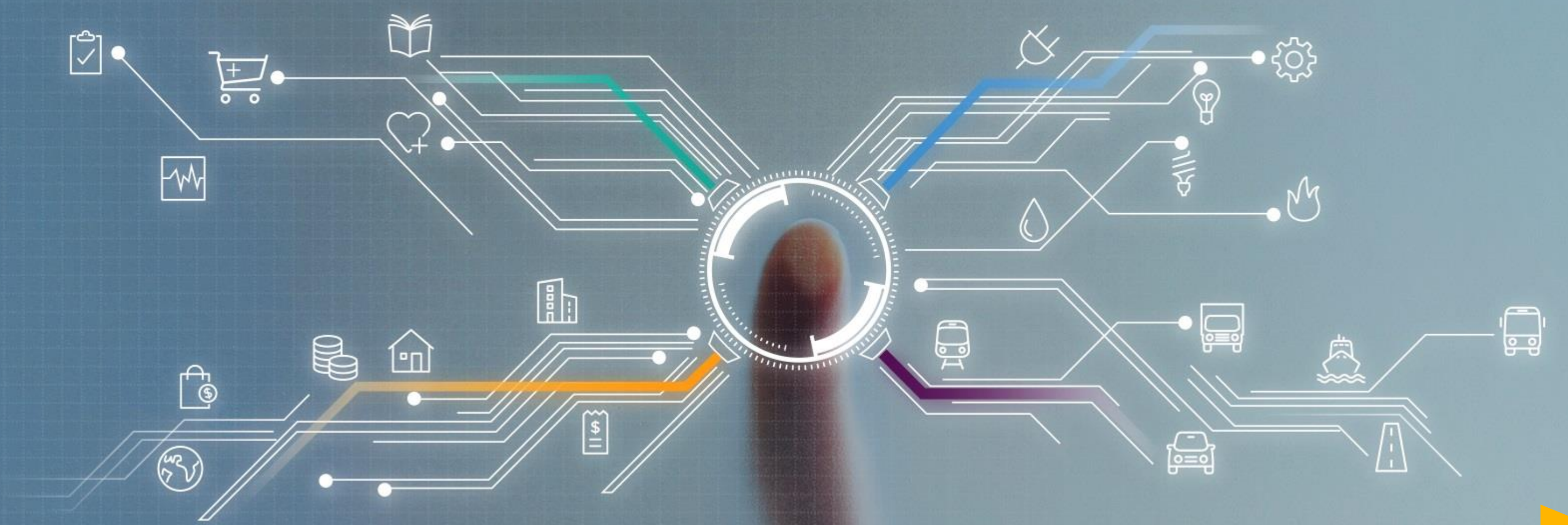
Strategy | Digital | Technology | Operations



Submission to OGC's Underground Maps & Models RFI

March 2017

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RFI Response Contributions from Underground Infrastructure Mapping Team in Chicago

Value Tree & Value Quantification Method

The current state of underground mapping presents many issues and challenges. The value tree below outlines the major pain points for utilities and cities (based on customer inputs). We have outlined methods to quantify the dollar impact of each issue and potential sources of data for each quantification method.

Current issue of…	causes…	resulting in the following pain points…	Quantification methods	Potential sources of data
Inaccurate and incomplete existing underground asset data	Inability for multiple stakeholders to efficiently coordinate to make decisions	•**High amount of time spent on information retrieval**	Reduction in mean number of man-days for information retrieval process	Information retrieval process tracker
		•**Project approval delays**	Reduction in pre-project man-days	Contract approval process tracker
		•**Design costs (due to delays)**	Reduction in mean number of man-days for project designs	Bid documents
		•**Design costs (due to additional survey/ testing/ platting services)**	Mean cost of each service, number of additional paid services	Work orders
		•Liability concerns for approving projects	Reduction in time delay for approvals due to liability concerns, lawyer cost?	Contract approval process tracker
		•High effort of coordination among parties working on the same data set	Reduction in time spent on reviewing shared documents	Date stamps on email exchanges
		•Higher construction bids	Reduction in construction bid price due to better data available	Bid documents
	Utility conflicts or conflicts with geological structures	•**Construction cost (due to delays)**	Reduction in mean number of man-days for construction process	Construction project plan
		•**Construction costs (due to non-labor related services)**	Reduction in mean construction cost not related to labor, such as materials/waste removal/equipment costs	Construction cost tracker
		•**Adverse economic impact**	Business drop in customers/revenue	Market research
		• Increase in change orders	Reduction number of change orders per project, cost per change order	Construction project management documents
		•Increased time required for conflict resolution based on disparate plan formats	Reduction in mean number of man-days for conflict resolution	Construction issues and risks tracker
	Accidental damage to underground and above ground infrastructure	•**Risk to public and worker safety**	Reduction in number of public/worker incidents, average cost (legal, insurance, compensation) per incident	Construction issues and risks tracker, OSHA
		•Higher insurance costs	Reduction in number of claims, cost per claim	Utility claims department
		•Higher raw material costs	Reduction in mean construction cost related to raw materials	Construction cost tracker
		•Bad publicity and city image	Reduction in number of phone calls/complaints from city, cost per complaint	Citizen relationship management
Lack of security around sharing and coordinating data	Potential IP issues, confidentiality, data security issues	•Security/information sharing concerns delay projects	Reduction in pre-project man-days due to security concerns	Construction project plan
		•**Higher cost due to liability for data security breach**	Reduction in claims due to security violation, cost of claims	Utility claims department
		•Negative impact to company whose assets information are wrongly shared	Reduction in IP breaches and lawsuits	Legal department
Lack of open marketplace for underground infrastructure data	Inability to operationalize the data to create additional value	•Untapped revenue for value based permitting	Pricing by a unit metric (e.g. sf, duration, etc)	Other city approaches
		•Missed opportunity for creating value-added services based on complete/accurate data	Data subscription fees, number of business and end users	Market research

High priority pain points

Underground Infrastructure Mapping (UIM) Technology Approach

Our proposed approach is a cloud-based GIS data management system that displays 3D underground data to users

Users

Municipalities
Utilities
Plan/Design Firms
Engineering Contractors
Construction Workers
Emergency Responders

Security and Access Management

Visualization/Applications

UIM Interface

Visualize data on a map
Upload CAD data
Download data into CAD format

Other Systems & Applications

APIs

Data Management

Common 3D Asset Database

GIS & attribute data management
Data processing
Data organization
Cloud-based hosting & storage
Security

Data Inputs

CAD files: DWG, SHP, DGN formats

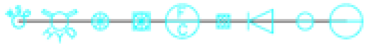
CAD Submission Standards

To ensure that the Underground Mapping platform contains updated, complete, and accurate data, we are enforcing CAD submission standards. All incoming CAD files should comply with the following standards:

1. **File must contain a basemap reference point**
2. **Utility lines and pipes should have the following attributes:**
   - OWNER
   - SOURCE
   - STATE
   - CONDUIT_SIZE
   - PACKAGE_SIZE
   - PACKAGE_CONFIG
   - TYPE
   - MATERIAL
   - DATE_INSTALLED
   - SUE_LEVEL
   - COVER DEPTH

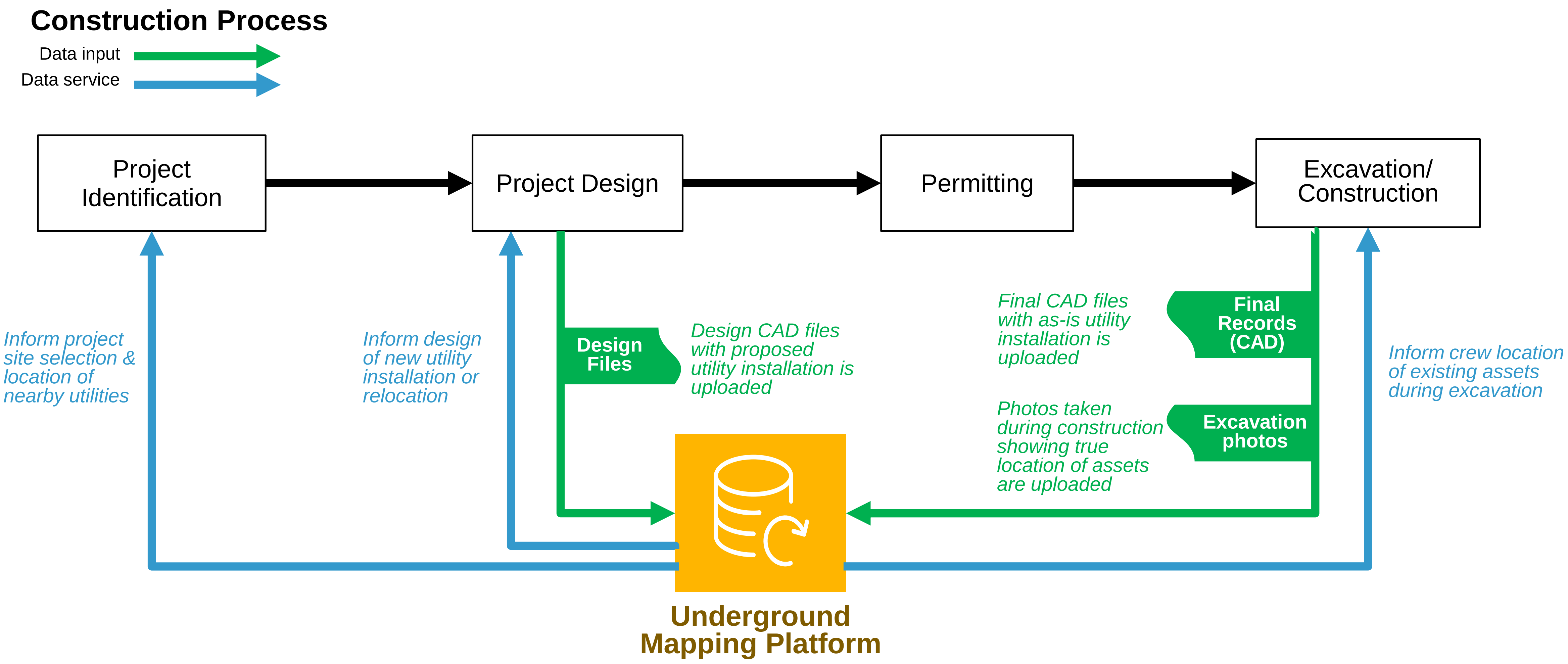
3. **Utility manholes should have the following attributes:**
   - OWNER
   - SOURCE
   - STATE
   - SIZE
   - TYPE
   - MATERIAL
   - DATE_INSTALLED
   - NUMBER
   - OFFSET
   - SUE_LEVEL

4. **Colors and lines for all CAD files submitted regardless of submitting entity should follow a set of standard guidelines**
   For example:

UTILITY	COLOR IN CAD FILE	LINE TYPES	NODE TYPES
ELECTRIC	RED		
WATER	CYAN		
GAS	GRAY		
TELCO	ORANGE		

Technology & Process

The Underground Mapping platform is used in multiple stages of the construction process, including project identification, design, and excavation/construction. Each new construction project generates new data (design documents, final records, photos) that are required to be uploaded to the platform. This ensure that the platform is self-maintained and self-building, containing the most updated data.



Ground Scanning & Sensing Technology to Capture Data

In addition to consuming CAD (DWG, DGN) files, the mapping platform should also ingest data from scanning technologies and sensing technologies. This allow engineers to verify the location of the asset as indicated in the design files against the 'ground-truthing' data from the scanning & sensing technologies. Below is a non-exhaustive list of these technologies.

Value (Accuracy / Information)

#	Sensor Technology	Description
1	Radio-Acoustic	Locate and detect underground water pipes by inserting a mobile acoustic sensor into the pipe, which moves with the water and wirelessly sends data to base station
2	Magnetic Induction	Deploy sensors along the pipelines that transmit data using MI-based communication mechanism; the system is best used for detecting and locating pipe leakages.

#	Scanning Technology	Description
1	LiDAR	Measures distance by illuminating a target with a laser and analyzing the reflected light
2	Infrared	Identify underground structures by detecting temperature differentials between the structure and surrounding environment
3	High definition cameras	Point cloud and geo-referencing solution using lower cost cameras. Also includes conversion to design ready vector formats
4	Handheld laser scanners (e.g. FARO)	Handheld devices that scans structures and objects and creates high-definition 3D point clouds, but need extensions to geo-reference the data
6	Mobile laser scanners	Scans structures and objects and creates high-definition 3D point clouds with camera system and GIS capabilities

#	Survey Technology	Description
1	GPR	Sends continuous electromagnetic pulses, receives the reflected waves back from subsurface structures, and displays the results to construct a "picture"
2	Electromagnetic	Receiver combined with an EM transmitter with a signal either applied to a line or induced via the soils

Photos for Construction Documentation

One of the most cost effective scanning technologies to implement is high-definition cameras that capture photos of the excavation site. These photos provides visibility to actual location of pipes. Engineers can overlay these photos on top of the GIS data and verify the GIS data.

Photo Documentation & Data Verification Process

Take photos during excavation → Convert photos into point cloud images → Overlay point cloud images with data in GIS platform → Edit data in GIS platform

Photo Documentation Tips

- Go around the entire excavation scene to do a comprehensive capture
- Pipes must be exposed
- Include markers in the area if possible
- Take multiples photos. Depending on the size of the excavation, may need >100 photos. Photos should overlap by 60%

RFI Response Contributions from Columbia University

Three-Dimensional Mapping of Underground Soils in New York City

Contact: George Deodatis, Columbia University

<u>Importance</u>: A critical part of the overall project of mapping the underground infrastructure of New York City in 3D is the mapping of underground soils. Every component of the underground infrastructure (e.g. train and car tunnels, water distribution pipes, telecommunications, sewers, building foundations, power lines, gas lines, etc.) is surrounded by soil. Some of these components are very close to each other or even in contact with each other. Consequently, the behavior of the entire underground infrastructure is critically depending on the type of surrounding soil. Three representative examples are mentioned here:

1) **Underground explosions**: an underground explosion in a gas line will affect other surrounding components of the infrastructure in different ways depending on the type of soil at that specific location. Some types of soils can dampen an explosion much better than others.
2) **Settlements of various components of the underground infrastructure**: different types of soils are susceptible to short- and long-term settlements to very different degrees. Settlements can have a devastating effect on the underground infrastructure.
3) **Deterioration of underground infrastructure**: different types of soils can promote deterioration and aging of the underground infrastructure to dramatically different degrees, especially when water is present.

There is a large number of other examples where detailed knowledge of underground soils is critically important for the behavior of buried utilities, tunnels and foundations, both under normal and under extreme conditions. Good infrastructure data combined with a detailed geology layer would enable the **modeling of a number of accident and disaster scenarios**. Analytics can be used to **predict** areas where infrastructure damage was more likely and **recommend** replacement and materials strategies.

<u>Methodology</u>: the main tool for determining the types of underground soils, the presence of water, and the depth to the bedrock is through so-called "**geotechnical borings**". Thousands of such borings have been performed over the years in New York City. The majority constitute proprietary information of private consulting firms. The PI (George Deodatis) has collected from earlier research one of the largest sets of geotechnical borings in New York City that can be used for the purposes of this project.

However, underground soils are highly heterogeneous and the potential presence of underground water further complicates the situation. Although a large number of geotechnical borings exist, they are still sampling only a small percentage of the underground soil mass. The key here is the **"educated" interpolation of soil properties in between the existing geotechnical borings**. There is a range of methodologies that have been developed along these lines based on the mathematical theory of "random fields" (soil properties are modeled as random fields in three dimensions). The PI (George Deodatis) has conducted extensive research work along these lines over the years and is perfectly suited to perform this task.

<u>Deliverables</u>: a complete **three-dimensional representation of underground soils** in New York City including the **identification of underground water and the depth to bedrock**.

Advanced Geophysical Mapping, 4-D Sensing, and Data Analytics in the Real Time Integrated Mapping of Smart Cities

COLUMBIA UNIVERSITY

Contact: Albert Boulanger, Center for Computational Learning Systems, Columbia University

The Smart-X {Cities, Buildings Grids} Group in the Center for Computational Learning Systems proposes regular, and where appropriate, continuous **geophysical mapping and monitoring of underground infrastructure** to enhance situational awareness and forecasting, and predictions to compliment Accenture's Underground Infrastructure Mapping platform.

Geophysical methods, especially when combined with themselves and others like vibro-acoustics offers **low cost means to repeatedly survey the underground** – not only buried utilities but physical properties of the embedding matrix. Initiatives in the UK and US have proven the value of these methods, in combination together, to map underground infrastructure. These methods are not perfect but compliment the traditional CAD/CAM & GIS paths to mapping the underground and often offer solutions to technical or "political" boundaries to traditional methods. They also offer a separate information source to help validate location and discover the unmapped.

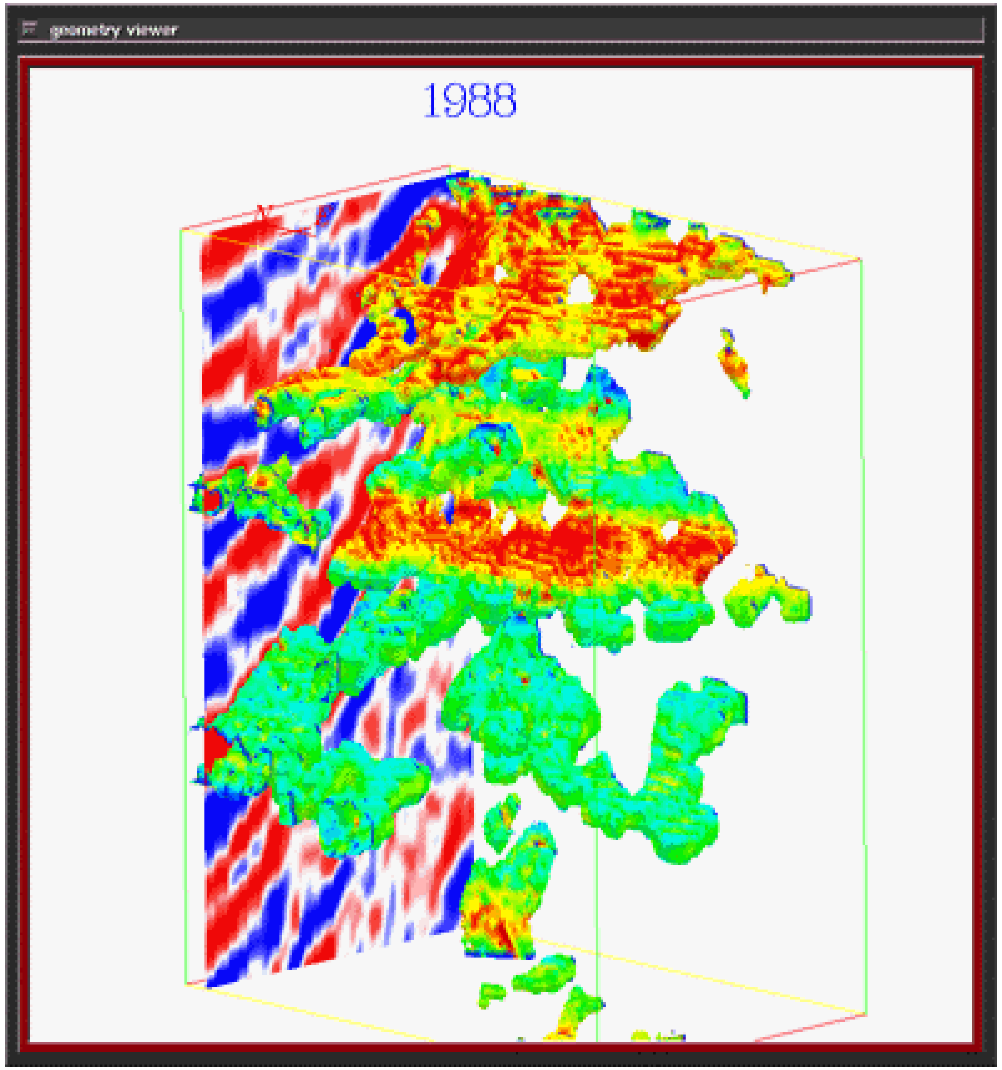
The Smart-X {Cities, Buildings Grids} Group had pioneered a **4-D (or time-lapse) method to use geophysical data to monitor for changes over time** in underground "structures" in the 90's when we were at Columbia's Lamont-Doherty Earth Observatory. Our group primarily used seismic data for oil and gas applications but also used it with ground penetrating radar (GPR) data. The method used 3-D segmentation to isolate voxels contained in structures of interest to collect just their statistics for advanced analysis. For example, to study a tetrachloroethylene spill using (GPR), one can isolate the spill plume structure and deduce and analyze properties just within the structure.

Our group's expertise is **machine learning, statistics, and data analytics on large datasets**. These datasets also come from real time monitoring applications, like smart buildings and grids. We are poised to process real time sensing data of underground structures and extract properties of structures of interest or in the embedding matrix and monitor changes. A major development in machine learning is the development of deep learning which is hitting new watermarks in accuracy and predictability. Deep learning combined with big data ingest is making advances where little progress has been made in the application of prior machine learning methods – for example, deep learning to predict earthquakes making use of data ingest from a physical model of the earthquake process.

We propose to apply and further develop advanced geophysical mapping, 4-D sensing, and data analytics in the real time integrated mapping of smart cities in a study area centered on Columbia's Manhattanville development. The 125th Street fault runs though the development and adds impetus to the monitoring of the area.

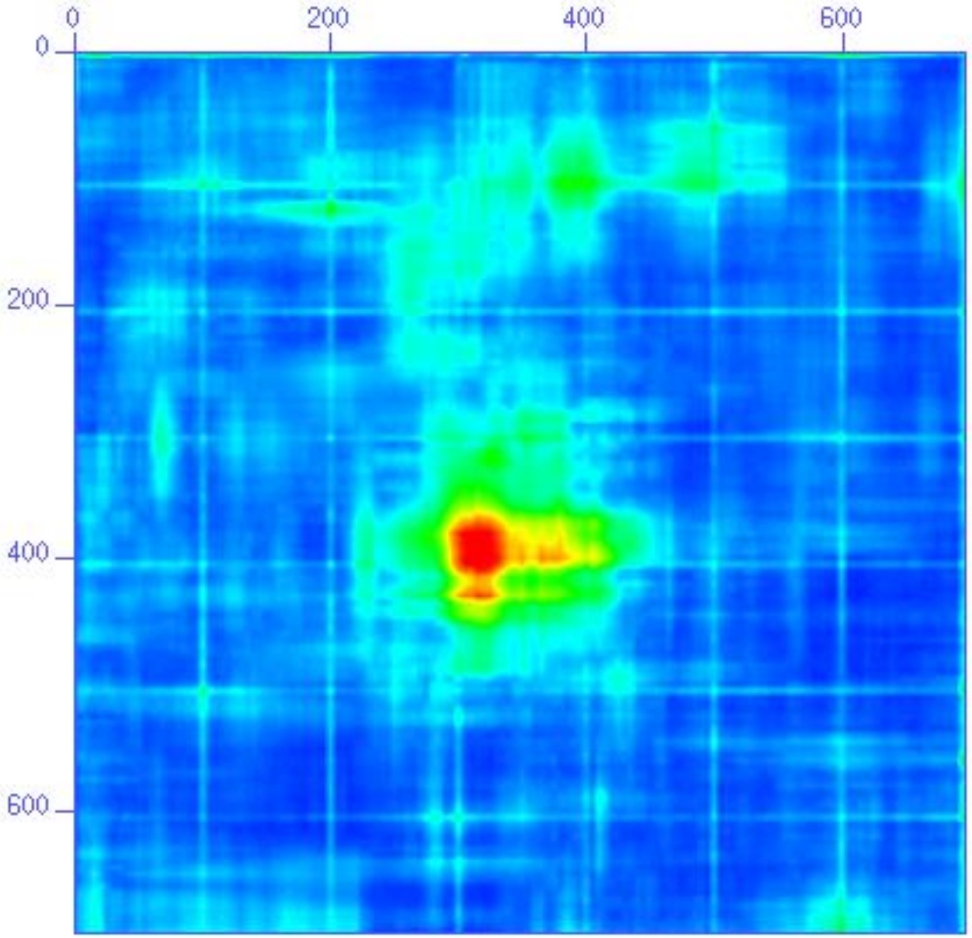
4-D Monitors Shrinkage Due to Production

Examples of 4-D (Time Lapse) Processing



Oil and Gas stacked reservoirs isolated by region growing in a 1988 seismic survey and 1994 survey. Changes in oil, gas, and, water content as well as shrinkage of the stacked reservoir are easily identified.

4-D applied to construction of hydrologic conductivity model



Time slice – 72

By tracking the DNAPL through the cube of data (actually here only 1.5 meter of the 2.5 meter is shown) we can determine what the path was that the DNAPL took through the sand. This path is considered to be a hydrologic conductive zone, and by inference, must have some different properties from adjacent zones which were not invaded by the DNAPL. The Movie is a series of time slices (or depth slices) through this hydrologic model. The index corresponds with the depth (from top sand)