Geolocating Underground Utility Infrastructure

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Worldwide Infrastructure Expenditure 2005-2030

$24 trillion to $53 trillion

Source: Booz Allen Hamilton, Global Infrastructure Partners, World Energy Outlook, Organisation for Economic Co-operation and Development (OECD), Boeing, Drewry Shipping Consultants, U.S. Department of Transportation

http://www.strategy-business.com/article/07104?pg=all
Navigant predicts that geospatial will become a foundational technology of smart grid

“The smart grid is all about situation awareness and effective anticipation of and response to events that might disrupt the performance of the power grid. Since spatial data underlies everything an electric utility does, GIS is the only foundational view that can potentially link every operational activity of an electric utility including design and construction, asset management, workforce management, and outage management as well as supervisory control and data acquisition (SCADA), distribution management systems (DMSs), renewables, and strategy planning.”

http://www.navigantresearch.com/research/utility-geographic-information-systems
Utility GIS to grow 12.8% per year reaching $3.7 billion in 2017

GIS is a critical technology to bringing information technology (IT) and operations technology (OT) sides of the business together.

- Projected annual growth rate (CAGR) of 12.8%,
- $1.8 billion in 2011
- $3.7 billion in 2017 (est.)

- Forecasts accelerating penetration of GIS into smart grid workflow applications - MWFM, DMS, energy mgmt (EMS), outage mgmt OMS, customer information (CIS), and analytics
- Growth, but at a slower rate, in GIS in utility construction and engineering-related GIS applications
  - Led by the power grid build-out in Asia Pacific.

http://www.navigantresearch.com/research/utility-geographic-information-systems
Utilities are using new geospatial data collection tools
New geospatial data sources used by utilities

High resolution aerial photogrammetry

Oblique aerial photogrammetry

“Streetview”
LiDAR
Technologies for geolocating underground structures

- Electromagnetic conductivity (EM)
- Ground penetrating radar (GPR)
- Very low frequency (VLF) profiling - electrical resistivity imaging
- Borehole geophysical and video logging
- Crosshole seismic testing
- Seismic tomography
- Microgravity surveys
- Seismic refraction
- Magnetometry
Ground penetrating radar (GPR)

Image: Ditch Witch

LandRay

Between The Poles
Standard tools for subsurface utility engineering (SUE)

- Electromagnetic conductivity (EM)
  - Metallic objects only
  - Requires putting a high frequency signal down the metallic object
  - Currently the most widely used in the electric power industry

- Ground-penetrating radar (GPR)
  - Most rapidly developing field
  - Tremendous progress over the past 20 years
Ground penetrating radar – Some applns

- concrete inspection
- underground utility detecting
- asphalt pavement inspection
- bridge deck and concrete inspection
- railroad ballast inspection
- geological fault detection and investigation
- tunnel scanning
- archaeology
- road inspection
- rebar detection and mapping
- landmine detection,
- snow scanning
- borehole inspection
- pavement thickness and road condition assessment
Ground penetrating radar - Market

- Largest manufacturers of GPR equipment are Mala Geoscience, Sweden; Geophysical Survey Systems, Inc. (GSSI), U.S.A.; Sensors and Software, Inc., Canada; US Radar Sub-Surface Imaging Systems, U.S.A. and Ingegneria Dei Sistemi (IDS), Italy

- Many niche players

- Spar Point report in 2005 - annual worldwide market for GPR hardware and software was about $50 million in 2005 and growing between 10% and 15% annually

- Could be as high as $100 and $200 million now.

- GPR associated services market estimated to be 5 to 10 times the size of the market for hardware and software solutions - roughly a $1 billion annually
Geolocating underground utilities
Problem: Underground utility hits in the U.S.

- Underground utility line hit every 60 seconds
- Annual cost of utility damage estimated in the billions

Reasons

- Inaccurate records (as-builts) and locating
- Utilities not marked
- Crowding within the right-of-way
Uncertainty about gelocation of underground infrastructure adds risk to construction projects

- Buildings
- Transportation infrastructure
- Utility infrastructure
- Every state has a Call-before-you-dig or One-call centre
- Location services cost utilities billions per year
Standards for geolocating underground utility infrastructure
Standards for subsurface utility location (US)

American Society of Civil Engineers (ASCE) Standard 38-02
"Standard Guideline for the Collection and Depiction of Existing Subsurface Utility Data“ – Quality Levels

- QL D - Review of Existing Records & Information
- QL C - Surveying & plotting above ground (surficial) features and connecting points
- QL B - Surface geophysical methods to map subsurface utilities
- QL A - Non-destructive excavation to expose & survey subsurface utilities, typically by potholing

The classification system is based on classifying the reliability of the location about subsurface facilities depending on the means by which the subsurface information was obtained.
Standards for subsurface utility location (UK)

PAS128

- QL D - Location of underground structures determined by a review of existing utility (paper) records
- QL C - A physical reconnaissance of the site has been performed identifying features of the network are visible above ground
- QL B - Remote detection technology such as electromagnetic or ground penetrating radar have been used to detect the location of the underground facilities.
  - QL B1-B4 specifies the precision of the measurements. For example, B3 corresponds to +/- 0.5 meters.
- QL A - Verification, typically by potholing
Standards for subsurface utility location (France)

The French Decree defines three levels of cartographic accuracy for underground structures:

- **Class A**: Maximum uncertainty of location is less than or equal to 40 cm
- **Class B**: Maximum uncertainty of location is greater than Class A and less than or equal to 1.5 meters
- **Class C**: Maximum uncertainty of location is greater than 1.5 meters, or if the utility operator is not able to provide the location.

Uncertainty in the geographical location of a structure is considered likely to jeopardize the construction project or significantly impact the technical or financial conditions of its implementation when the geolocation of the structure is classified in accuracy classes B or C.
Standards for subsurface utility location (Heathrow)

Heathrow's confidence codes are a way of classifying the results of underground utility detection, verification and location undertaken by different survey methods:

- **D** – Desk top survey followed up with site reconnaissance.
- **C** – Use of underground scanning tools to locate services with a reasonable degree of confidence of what has been located.
- **B** – Detection - Use of two techniques to verify the location of the utility, for example, using Ground Penetrating Radar (GPR) to confirm the location found with an electromagnetic scanner.
- **A** – Verification - Digging a trial hole using a vacuum excavation/air pick or hand tools to expose the service, then surveying the location and extents to 25mm accuracy.
Case studies: geolocating underground utility infrastructure
Region of Lombardy (Milan)
Geolocating underground infrastructure: Lombardy/Milan

Pilot project on the site of the Expo Milano 2015

- Total project area 230 000 square meters.

- All underground infrastructure
  - electric power, water, sewers, gas, district heating, street lighting, and telecommunication, were mapped both from historical records and using ground penetrating radar (GPR).

- Data model for underground infrastructure developed for the different types of underground networks
  - based on Italian DigitPA and the INSPIRE-US utility standards.

- Most data 2D, but some 3D data recorded and used to demonstrate 3D visualization
Geolocating underground infrastructure: Lombardy/Milan

Comparison of historical records with GPR results

- Thousands of meters of unknown infrastructure.
- For known infrastructure - average error in geolocation was about 30%, but much larger errors of up to 100% were also recorded.
- Conclusion: even in Europe record of underground infrastructure can be highly unreliable.
- Benefit to municipalities: identifying underground infrastructure previously unknown provides financial motivation for municipalities because they tax utilities based on the total infrastructure the utilities maintain within city limits.
- Data made available on the Web via Open Geospatial Consortium (OGC) standards (WMS, WFS, KML).
Comparison of GPR measurements and the historical record for pilot project in Milan, Lombardy, Italy

<table>
<thead>
<tr>
<th>Utility</th>
<th>From GPR Survey (linear meters)</th>
<th>From Historical Records (linear meters)</th>
<th>Difference (linear meters)</th>
<th>Difference (percentage)</th>
</tr>
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<tbody>
<tr>
<td>TLC</td>
<td>37.385</td>
<td>32.681</td>
<td>4.704</td>
<td>14%</td>
</tr>
<tr>
<td>Water</td>
<td>21.055</td>
<td>19.744</td>
<td>1.311</td>
<td>7%</td>
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<tr>
<td>Sewage</td>
<td>28.622</td>
<td>20.355</td>
<td>8.267</td>
<td>41%</td>
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<tr>
<td>Gas</td>
<td>22.592</td>
<td>23.467</td>
<td>-875</td>
<td>-4%</td>
</tr>
<tr>
<td>Energy</td>
<td>39.525</td>
<td>35.960</td>
<td>3.565</td>
<td>10%</td>
</tr>
<tr>
<td>Unknown</td>
<td>22.271</td>
<td>-</td>
<td>22.271</td>
<td>100%</td>
</tr>
<tr>
<td>Not in use</td>
<td>3.908</td>
<td>-</td>
<td>3.908</td>
<td>100%</td>
</tr>
<tr>
<td>District heating</td>
<td>7.192</td>
<td>4.284</td>
<td>2.908</td>
<td>68%</td>
</tr>
<tr>
<td>Total</td>
<td>182.550</td>
<td>136.491</td>
<td>46.059</td>
<td>34%</td>
</tr>
</tbody>
</table>

*32% is the average discrepancy between historical and instrumental dataset calculated on a matching boundary of one meter.*

Total project survey areas
ROI for improved information about underground infrastructure

Return on investment (ROI)

€16 for every € invested

Other benefits include improved safety for workers and the public and fewer traffic disruptions.
Geolocating underground infrastructure: Lombardy/Milan

Lessons learned

- Clear legal framework is absolutely essential.
- Necessary to ensure that all stakeholders are involved - EU, national, regional, provincial, and municipal governments.
- Absolutely critical to the success of the project was non-destructive, non-disruptive technology for accurately detecting underground infrastructure.

As a result of the successful pilot project it was made mandatory for all municipalities in Lombardy, which includes about 1500 towns, to map their underground infrastructure using GPR.
Heathrow Airport

Would you like to dig here?

Knowing What, Where and the Status of quality data is critical for our business
Geolocating underground infrastructure: Heathrow

- Average 181,000 passengers per day
- 13 different types of infrastructure
- 45,000 man holes
- 72 miles of high pressure fire water mains
- 81 miles of aviation fuel pipelines
- Power cables ranging from 9V up to 400 kV.

Even a minor accident carries the risk of serious consequences.
Geolocating underground infrastructure: Heathrow

Motivation

- Primary reason for accurately geolocating underground infrastructure is safety
- Legal and contractual requirements, such as CDM (Construction Design Management) Act and Corporate Manslaughter Act
- Efficiency
Heathrow Map Live project

Goal - reduce incidents involving hitting utilities during excavation by improving data reliability and accessibility

Implemented Common Data Environment (CDE)
- Data is created once only and used many times.
- Standards, guidelines, and work processes are designed to support a single point of truth
- Each data element has a single owner and is shared across the organization

Business benefit of a common data environment
- Minimizes rework
- Increases re-use of designs
- Efficient handover from design and construction to operations
Data quality

Safety is Heathrow's first concern, so data quality is a top priority.

- Emergency response - Reliable data about infrastructure is required for emergency response

- Avoiding utility hits during excavation – Essential to provide accurate location of existing infrastructure to more than a thousand contractors working at Heathrow at any given time.

- 2002 - 40% of underground facilities mapped to half a meter
- 2012 - 72% of underground facilities mapped to half a meter
Continuous data quality improvement

Validation Life Cycle

- Information fully integrated into existing information
- Project Manager sets scope and requests latest information
- Designer receives existing information
- Designer carries out site reconnaissance and applies confidence codes
- Designer/Client/Project Manager agree scope for survey
- Survey carried out, increasing confidence codes
- Design completed, survey and design passed to constructor
- Constructor surveys as they go increasing confidence codes
- Progressive handover to client for integration
Heathrow’s Validation Lifecycle

- Project manager sets scope and requests latest information
- Designer receives existing information
- Designer carries out site reconnaissance, applies confidence codes
- Designer/client/project manager agree on scope for survey
- Survey carried out increasing confidence codes
- Design completed, survey and design passed to constructor(contractor)
- Constructor surveys as they go increasing confidence codes
- Progressive handover to client for integration
- Information fully integrated into existing information
Heathrow Benefits from improved geolocation of underground infrastructure

Service strikes (utility hits) due to inaccurate information about underground infrastructure have declined at Heathrow by a factor of 6 since 2002.

Next steps

- Going forward Heathrow is planning to implement a "Base Station", an application which will be mandatory for all contractors.
- In the future Heathrow will only accept “as-built” information that is created using the Base Station application.
- Heathrow is supporting development of the PAS128 standard.
Las Vegas 3D infrastructure model
Las Vegas 3D above- and below-ground infrastructure model

Five years ago the City of Las Vegas became interested in 3D modeling

- Local consulting firm provided education, working with the city and utility agencies to introduce them to 3D modeling and visualization technology.

- Included workshops with the city and utility agencies to understand business problems they were facing.

Major problem identified repeatedly in these workshops, by City but also by utilities - hitting underground infrastructure during excavations.
Challenge: subsurface utility engineering (SUE)

Underground utility line hit on average every 60 seconds – national statistics U.S.

- 2D as-builts of underground infrastructure are unreliable
  - In most municipalities in North America, underground utility lines have been put in the ground not according to plan but wherever it has been easiest and cheapest to build them

In Las Vegas location of underground utilities is very poorly known.

- City of Las Vegas decided to go ahead with a pilot project to model one and half miles of Main Street in the older part of Las Vegas.
- The project was intended to model below and above ground facilities including roadways, utilities and telecommunications, and buildings.
  - The project also specified implementation of a new low distortion geospatial coordinate system to make it possible to support engineering grade accuracy for geolocating infrastructure.
Legal Basis

City of Las Vegas owns most of the right of ways (ROW) within Las Vegas proper

- Passed By-law mandating that contractors required to use open trenching for utilities

- All work has to be surveyed before the trench is closed.
Reality capture for Las Vegas Model

- **Buildings**
  - Extrude building footprint from a GIS,
  - Building models from Sketchup 3D Warehouse,
  - Laser scan existing structures
  - Complete BIM models for newer buildings provided by architects.

- **Below ground facilities**
  - Existing design records (drawings)
  - Survey of associated surface structure
  - Ground penetrating radar (GPR)
  - Test holes

- **Above ground utilities**
  - Mobile laser scanning combined with GIS data
Las Vegas Augmented Reality Appln

WORKFLOW

3D Intelligent City Infrastructure
Benefits of Las Vegas 3D Infrastructure Model

- Reduced risk of unexpectedly hitting underground utilities especially hazardous ones like gas mains during construction
  - Improved safety
  - Lower costs
- Enables automated clash detection to identify potential problems during design phase of construction projects
- Reduced operating costs resulting from fewer truck rolls for cable/pipe locate operations.

City has concluded that the 3D model approach provides more information per dollar invested.

As a result of the success of the initial project the city has proceeded with a second much larger project that expands the area of coverage by a factor of six.
ROI of improved geolocation of underground facilities
ROI for improved information about underground infrastructure (North America, retrospective)

1999 Purdue University US$4.62  
For US DOT

2004 University of Toronto C$3.41  
For Ontario Sewer and Watermain Contractors Association

2007 Penn State University US$21.00  
For Penn DOT

2010 University of Toronto C$2.05 to $6.59

Lombardy, Italy - Estimated return on investment of €16 for every € invested.
International efforts to geolocate underground infrastructure
International Efforts to Geolocate Underground Facilities

- **Tokyo, Japan** (now deployed in major Japanese cities) – Many years ago Tokyo developed the mainframe-based Road Administration Information Center (ROADIC) system.

- **Sarajevo, Bosnia** – Over 40 years ago as part of the permitting process, Sarajevo mandated the recording the location of all utility and telecommunications infrastructure in the city.

- **Calgary, Alberta** – A number of years ago the City Government passed a by-law which mandated that all utilities and telecoms working within city limits must provide data showing the geolocation of their infrastructure to the city's Joint Utility Mapping Project (JUMP).

- **State of Jalisco, Mexico** - The Instituto de Información Territorial del Estado de Jalisco developed an integrated infrastructure database for the State of Jalisco.

- **Edmonton, Alberta** - Edmonton, Alberta has a shared facilities mapping database.
International Efforts to Geolocate Underground Facilities (cont.)

- **Penang, Malaysia** – Penang's Sutra D'Bank (Penang State Government Subterranean Data Bank) is maintained by a joint venture company EQUARATER (PENANG).

- **Bahrain** - Bahrain's Intelligent Decision Support System (iDSS) provides a single repository for all underground facilities.

- **Sao Paulo, Brazil** – The City of Sao Paulo's GeoCONVIAS project integrates data from 20 to 30 utilities which operate in the city of Sao Paulo.

- **Rio de Janeiro, Brazil** - The City of Rio de Janeiro has a similar project GeoVias funded by the government of the City of Rio de Janeiro and four utilities.

- **France** – A nation-wide multi-billion euro project is underway to improve the quality of the geolocation information about France's underground utility infrastructure.
Utilities in highway construction
Current construction project lifecycle

- **Paper Plans**
- **Design**
- **Basemap**
- **Project Development Surveys**

1. **Construction Staking**
2. **New Projects**
3. **Existing Sites**
4. **As-Built Plans**

Ron Singh, Chief of Surveys, Oregon Department of Transportation
Utilities are a huge problem.

- The typical process is to go and do a complete survey of the area. This provides fairly reliable information about what is on the surface because it records what is out there right now.
- But it does not provide information about what is underground.
- Today, the utility companies help identify the utility infrastructure for us. They come and put paint marks on the road surface to show the location of the pipes and lines.
- Most of the time there is no depth information and the accuracy is typically plus or minus two feet [which is the level of accuracy that utilities are expected to deliver in Oregon].
- If the highway designer needs to know the location of underground utilities more accurately, we go out there with a backhoe, dig a hole and find the lines.
- The surveyor records the precise three dimensional position for that utility at that location. There are now technologies like ground penetrating radar (GPR) that allow you to locate underground utilities without digging, but from my vantage point it is still difficult to interpret and is very time-consuming.
“We need to stand the construction process on its head”

Ron Singh, Chief of Surveys, Oregon DOT
Future construction project lifecycle

Disruptive!
During and post-construction survey

- In this scenario, when we are building utilities or other structures underground, there are a number of tools that can be used to record a three-dimensional position for the pipes, cables or culverts.

- Then, as we build up the roadbed prism, we would be capturing all that information in 3D as the underground foundation is going in.

- This way, when we complete the project, we would not only have a new physical road, but also a new 3D digital as-built road.

- Over time, we would see more of these little pockets of 3D-engineered models that we could start using as the starting place for future designs.

- Years later, if we want to reconfigure this interchange, we do not have to do a full survey of the area again.
Intelligent highways

Critical elements

• Model-based design
  • 3D BIM models for highways
  • Includes utilities

• Engineering data archive
  • geospatially-enabled, 3D
  • accurate, up-to-date
  • provides 80-90% of what is required to initiate design

• Post-construction survey
  • Provides reliable 3D as-builts (typically BIM + imagery)
Modeling the Oregon Highway System

- Ron Singh: My goal is to cover our entire highway system with point clouds and oblique imagery, which can be overlaid with all the 3D asset information that comes from the new construction process.
Benefit: Autonomous vehicles

- Google 10+ vehicle fleet
- Driven 300,000 miles as of Aug 2012)

- Autonomous vehicles will be data hungry. Already cars are using real-time sensing of their location and what is around them. But I cannot imagine that they would not benefit from knowing about the highway infrastructure.

Ron Singh, Chief of Surveys, Oregon Department of Transportation
Some takeaways

Inaccurate information about underground infrastructure costs the world’s economies billions if not trillions every year

- Adds risk to every construction project

New technologies are providing reliable non-destructive tools for locating underground utilities

- Standards for the reliability of information about underground facilities have been developed

ROI of improving quality of geolocation of underground facilities estimated at up to $21 for every $ invested

- Cities, Regions, and Nations are beginning to realize the benefits of accurate geolocation of underground infrastructure
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http://geospatialblogs.com