Request for Information on Underground Infrastructure Mapping and Modeling

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The Open Geospatial Consortium (OGC®)
35 Main Street, Suite 5 Wayland, MA 01778 Telephone: +1-508-655-5858

Executive Summary

This Request For Information (RFI) seeks to gather information in support of a Concept Development Study (CDS) on mapping, modelling, capturing, analyzing and sharing data about underground infrastructure. The CDS will result in recommendations for developing and testing prototype standards in the next phases of an underground infrastructure data interoperability initiative.

Why? – the business/societal problem that the RFI and CDS will address

The cost and time required to build, maintain and improve underground assets is substantial to both the owner and other stakeholders who may interact with them. Underground infrastructure is a special information interoperability challenge because its location and condition is normally hidden by soil, pavement and other structures. Accurate three-dimensional geospatial information about the location, nature, condition and relationships of these assets would reduce the expense for the asset manager and other stakeholders. Holistic understanding of the relationships between underground assets and with above ground infrastructure is needed to minimize service breakdowns and mitigate the impact of disasters. Comprehensive, exchangeable and up-to-date datasets could benefit the following business and societal activities:

- Utility services operation and maintenance
- Emergency management and disaster response
- Construction planning and management
- Medium and long term planning for development, utilities, transport
- Information model foundations of smart cities.

These benefits would be realised by enabling a variety of efficiencies:

- Less damage to existing assets when undertaking works
- Better estimation of timescales earlier in the process
- Improved assessment of impacts and risks to other assets from planned activities
- More effective prevention of, preparation for and response to emergencies
- More accurate analysis, prediction, and prevention of cascading utilities failures
- More comprehensive analysis of options for continuity of service
- Better understanding of points of vulnerability within and between assets.
- More secure sharing of sensitive underground information

Numerous studies around the world have shown that these are common challenges in an increasingly urban and technical world. A recent study by the Ordnance Survey reports that "approximately £150 million is incurred directly by strike damage to third party assets alone by utilities across the UK with indirect costs around ten times this sum. Fatalities are a severe consequence with, for example, approximately 12 deaths and 600 serious injuries per year from contact with electricity cables." Modest improvements in knowledge of underground infrastructure are likely to pay significant dividends.

How? Responses being sought by the RFI

RFI responses could take several forms, for example:

- Relevant standards already in use
- Implementations tried including lessons learned
- Technologies existing and anticipated that enable data capture
- Dataset modeling and workflow processes for data management.
- Assessments of the potential benefits
- Recognition of potential risks in particular by identifying relations between features
- Understanding of current processes including legal requirements
- Simple confirmation that this is an issue
- Likely challenges
- Anything else of relevance

What? CDS results enabled by RFI responses

The Concept Development Study will be based upon the RFI responses and will examine opportunities for–and barriers to–establishing functional three-dimensional repositories of underground infrastructure and other relevant sub-surface information. The study will consider, among other issues, how different infrastructure data providers, consumers, and software vendors can best achieve:

- Sustainable collection of geo-enabled data fit for purpose on all relevant underground infrastructure.
- Exchange of data between platforms, systems, and organizations without loss of detail, attribution, or significance
- Interactive model-driven data access
- Enforcement of data security sufficient to protect appropriate public, private, and personal interests
- Integration of inputs from current and new generations of sensors and other intelligent infrastructure components
- Advanced data analysis including predictive analysis and big data analytics
- Continuity of data and systems where infrastructure exists and/or extends onto and above the ground surface

The CDS will also define the scope of a multi-phase underground infrastructure interoperability initiative. Subsequent phases will seek to develop a deeper understanding of implementation issues and test standards-based components for enabling infrastructure data interoperability in realistic application scenarios. Scenarios will initially focus on urban landscapes but will take suburban and regional environments into consideration as well.

Detailed instructions on how organizations can respond to the RFI and submit questions about it can be found at the end of the RFI document.

Table of Contents

1 Introduction

1.1 RFI purpose and scope

This Request for Information (RFI) is part of a Concept Development Study to assess the current state and future direction of information standards for modeling, mapping, and managing underground infrastructure.

The OGC Innovation Program utilizes a multi-step collaborative methodology for interoperability initiatives that seeks to uncover geospatial interoperability challenges and then develop ways to address them. The methodology begins with a Concept Development Study (CDS) in order to understand and frame the current state of information technology in a target knowledge domain. A critical step in a CDS involves gathering critical insights from domain experts and other stakeholders about productive future directions that can then be explored in subsequent initiative activities such as testbeds, experiments and pilots. Ultimately the initiative methodology leads to development and adoption of consensus reference architectures and information standards that increase both the value and the utility of geospatial information.

Readers of this RFI are encouraged to respond with recommendations to be considered for inclusion in best practices for Underground Infrastructure Mapping, Modeling, and Management. Recommendations may include technologies, system architectures, information models and vocabularies, as well as organizational practices and approaches to governance.

This Concept Development Study is governed by the OGC Interoperability Program Policy and Procedures[1].

1.2 Organizations supporting this RFI

Sponsors of the Concept Development Study:

Fund for the City of New York (FCNY) – The Fund was established by the Ford Foundation in 1968 with the mandate to improve the quality of life for all New Yorkers. For over four decades, in partnership with government agencies, nonprofit institutions and foundations, the Fund has developed and helped to implement innovations in policy, programs, practices and technology in order to advance the functioning of government and nonprofit organizations in New York City and beyond. The Fund has recently established the Center for Geospatial Innovation to develop and support initiatives that leverage the power of spatial data and technologies for the public good. https://www.fcny.org/fcny/about/

The Singapore Land Authority (SLA) – The Singapore Land Authority (SLA) is a statutory

[1] After following the link provided, see document OGC 05-127r8 for a summary of the OGC Interoperability Program - recently renamed the OGC Innovation Program.

board with the Ministry of Law. Its mission is to optimise land resources for the social and economic development of Singapore. Apart from its roles in land management, regulation and the national land registration authority, SLA drives the development of geospatial information science and technology as the national geospatial agency. SLA currently spearheads the 3D mapping and modelling of the entire city state which would contribute to the development of Virtual Singapore, the authoritative 3D digital platform for geospatial collaboration that supports Singapore's Smart Nation initiative.   www.sla.gov.sg

Ordnance Survey, Great Britain – Britain's mapping agency, Ordnance Survey makes the most up-to-date and accurate digital and paper maps of the country. Each day OS makes over 10,000 changes to its database of more than 500 million geographic features. Since 1791 OS data has been used to help governments, companies and individuals work more effectively both here and around the world. The information OS gathers helps keep the nation, economy and infrastructure moving. http://www.ordnancesurvey.co.uk/about/

Organization managing the Concept Development Study:

The **Open Geospatial Consortium** (**OGC**) is an international consortium of more than 500 companies, government agencies, research organizations, and universities participating in a consensus process to develop publicly available geospatial standards. OGC standards support interoperable solutions that "geo-enable" the Web, wireless and location-based services, and mainstream IT. OGC standards empower technology developers to make geospatial information and services accessible and useful with any application that needs to be geospatially enabled.

2 Underground Infrastructure Mapping and Modeling

2.1 Concept and Motivation

Over the past decades, Geospatial Information Systems and Technologies (GIST) have gained recognition as valuable tools that support a wide variety of essential operations and functions. Much of the power of GIST systems is based on their exceptional ability to integrate, visualize and analyze multiple data sets, by correlating them in space and time through the use of common location fields such as addresses and GPS positions. A significant part of the large-scale success of GIST is due to efforts, led by the Open Geospatial Consortium (OGC), to establish standards for geo-enabled information that facilitate data interchange and integration. Such standards make it possible for spatially enabled data to be accurately superimposed from many sources within a single area and connected across many adjoining areas.

Utility infrastructure data – both above and below ground – presents a significant challenge to the establishment of common spatial data standards and is a "last frontier" of sorts for the geospatial revolution. Within any metropolitan area there may be as many as eight or more different utility networks including water, sewer, gas, steam, and liquid petroleum products pipes; electric power and telecommunications lines; as well as all of the tracks, tunnels, bridges, conduits, and other structures that make up transit systems. Each of these networks likely is owned and managed by a different public or private organization and has unique engineering and technical characteristics that have evolved over many years. Originally separate manual record keeping systems have evolved over time to separate digital systems with incompatible software and data formats. Even different areas or systems within a single utility franchise may use distinct and incompatible ways of recording and managing information. These incompatibilities make efficient and timely data integration across different utilities difficult. Even when it is technically possible, utilities have often been reluctant to share their information for security, competitive and cultural reasons.

Above-ground infrastructure is at least straightforward to re-survey and validate. When infrastructure networks run underground, the problem of data incompatibilities is compounded further, because the structures themselves are invisible, covered over by street pavement and sidewalks, encased in different soil and sediment units. For many structures, especially older sewers and water mains, the exact locations may not even be known. Even less well known is the underground context of such structures, including electromagnetic fields, chemicals, moisture, heat, cold, geological faults, subsidence, vibration, and so on. The presence and effect of water, whether as groundwater, seepage, or infiltration, is not only significant, but dynamic and hard to monitor. Most problematic of all, interactions between utilities structures are often unknown as a result, leading to electrified manhole covers and failures cascading unexpectedly from one network to others.

The problem would be more tractable if underground infrastructure networks never needed repair, maintenance, or replacement but in fact the exact opposite is the case. Across major cities like New York and London, hundreds of thousands of street excavations are done each year to fix, replace, or update infrastructure, as well as add new services where older infrastructure already exists. Ordnance Survey has collated existing research that indicates that approximately 4 million holes are dug each year by the UK utilities industry to repair, upgrade or provide new connections to their assets[2] .

At the present time, few if any cities have been able to comprehensively collect and integrate data about the underground infrastructure networks that serve their citizens. Drawings projected onto the street surface of underground utilities are regularly created on a piecemeal basis and with a very wide range of confidence. To reduce the likelihood of hitting utility structures during a street excavation under these circumstances, “One Call” and “Dig Safe” services exist to notify utilities that a prospective street opening has been marked *on the street itself*, and request that each utility visit the location to physically mark the location of their own lines *on the same street surface*. Alternatively, personnel from one utility must visit the map/drawing rooms of other utilities to do visual comparisons of structure location. Such manually intensive methods for integrating utility information add time and uncertainty to the construction process given the variable quality of old, inaccurate and incomplete records.

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[2] https://geovation.uk/wp-content/uploads/2017/01/A00031-Deep-Dig-Booklet_UPDATE.pdf, also see Beck, R., Fu, G., Cohn, A., Bennett, B. and Stell, J. (2007) ‘A framework for utility data integration in the UK’, in Coors, M., Rumor, M., Fendel, E. and Zlatanova, S. (eds) Urban Data Management Society Symposium, (Stuttgart, Germany, October 2007).

The Ordnance Survey's Geovation Challenge 2016[3] has collated information from many different sources and reports that "Approximately £150 million is incurred by strike damage to third party assets alone by utilities across the UK with indirect costs around ten times this. Fatalities are a severe consequence, with for example, approximately 12 deaths and 600 serious injuries per year from contact with electricity cables. Furthermore, In emergency situations, the inability to quickly and accurately integrate quality data from multiple utilities can result in greater damage, larger outages and unnecessary injuries and deaths."

2.2 RFI Objectives

The objective of this Request for Information is to gather inputs for a CDS to examine how infrastructure data providers, consumers, and software vendors might accomplish:

- Sustainable collection of geo-enabled data fit for purpose on all relevant underground infrastructure.
- Exchange of data between platforms, systems, and organizations without loss of detail, attribution or significance
- Interactive model-driven access to infrastructure data
- Enforcement of data security sufficient to protect appropriate public, private, and personal interests
- Integration of inputs from current and new generations of sensors and other intelligent infrastructure components
- Advanced data analysis including predictive analytics and big data analytics
- Continuity of data and systems where infrastructure exists and/or extends onto and above the ground surface

The purpose of the CDS will be to develop and document an in-depth understanding of all the components necessary to enable infrastructure data interoperability and standards in an underground environment, initially focused on the urban landscape but extendable to broader regions; this Request for Information (RFI) forms a key part of the CDS process. The responses will be compiled, analyzed, and used to inform the final CDS report which will include a full set of use cases, architectural options, promising technologies, and other relevant information. The CDS will in turn define the scope for subsequent steps of a multi-phase underground infrastructure interoperability initiative that is able to both develop and demonstrate the value of common information standards and practices.

2.3 Applications and benefits

Through the Underground Infrastructure initiative, OGC and its members seek to lower the barriers to interchange and integration of infrastructure data in a number of critical applications. By means of a common, extensible data model and interchange standards, OGC expects to create a favorable environment that encourages uniform, high quality data development and enables straightforward, timely data integration. This will eventually make it possible to assemble complete "common operating pictures" of what is underground

[3] https://geovation.uk/research/underground-asset-challenge-deep-dig/

whenever and wherever needed. This should lead to large-scale efficiencies in the way that the “underground city” supports the life of a city as a whole.

Benefits in specific applications include:

1. **Application: Data Creation and Secure Sharing:** One of the reasons utilities resist sharing their data is the concern that they will be obliged to convert their data at significant expense into the format of requesting organizations. The creation of common data interoperability standards will reduce data conversion requirements and costs. Sharing of the data must also be done in a secure fashion to prevent inappropriate use of this critical data.

   Benefits: After getting their data to conform to interoperability standards, utilities will be able to share and integrate their data seamlessly with other utilities, without loss of information or functionality. When security concerns are addressed, the ease and lower costs, increased reliability, and greater speed of sharing will encourage utilities to collaborate with one another and with other organizations.

2. **Application: Street Excavations:** Using up-to-date methods of data exchange, including wireless communications to mobile devices in the field, will make it possible to rapidly assemble information about all the infrastructure elements in the vicinity of an intended street opening.

   Benefits: Reduce the time required to determine the locations of vulnerable or conflicting structures locations before excavating. Minimize the number of street openings by coordinating different utility projects and street repavement activities. Reduce the number of accidental utility strikes, which will reduce service outages, repair costs, injuries, and even loss of life.

   Example from Ordnance Survey: London’s Heathrow airport has an abundance of underground assets – including 45,000 manholes, 115 km of water mains and 130 km of fuel pipelines – serving over 180,000 visitors per day. In 2002 only 40% of their underground assets were mapped to within half a metre; major mapping work between 2002 and 2011 reduced asset strike incidents due to inaccurate data by over 80% (Ordnance Survey’s Geovation Challenge 2016 collated information).

3. **Application: Preventive Maintenance**: With comprehensive underground utility information (including age, material, thickness, depth, etc.) plus accurate information about soils and other conditions, it will be possible to develop more effective predictive models, maintenance strategies, and replacement schedules. New techniques in geospatially enabled “big data analytics” may also enable engineers and planners to extract unexpected, beneficial intelligence from utility operations and sensor data streams.

   Benefits: Reduce the occurrence of utility breaks, which can be very expensive, by monitoring those features thought to be most likely to fail and by designing a replacement strategy that targets the most vulnerable features.

4. **Application: Large Scale Development and Long Term Planning:** Major development projects such as new subway lines and new building complexes require continuous access to large amounts of accurate and up to date underground infrastructure data in order to decrease costs and design challenges, as well as minimize the risk of utility strikes and discovery of unexpected interferences. Poor infrastructure data is often cited as a major cause of project delays, change orders and increased costs.

   Benefits: Cost increases due to the delays caused by faulty and inadequate information could be in the vicinity of 1% per month. Inaccurate infrastructure information may also cause planners to miscalculate project requirements and lead to expensive design modifications.

   Example from Ordnance Survey: A third of utility construction projects that overrun are estimated to be due to limited access to high quality, geospatial data and errors in interpretation of data (Ordnance Survey's Geovation Challenge 2016 collated information).

5. **Application: Emergency Response:** Failures in large capacity infrastructure elements like transmission lines for water, gas, electric power, steam and sewer systems pose significant risks, particularly in dense urban neighborhoods, of widespread service losses and cascading effects. Rapid access to accurate information about the location of these failures and surrounding structures that may be affected can allow quick action to be taken to limit the scope of damage and minimize the effort required to restore services. Analysis of all nearby underground and aboveground features enables analysis to identify possible cascading failures.

   Benefit: Permits the rapid diagnosis of major problems. Reduces the damaged caused by major infrastructure failures by being able to inform emergency responders about underground conditions and infrastructure placement. For example: Stopping water flow from a major water main break by rapid access to the proper shut off valves can save millions of dollars per minute. Identifying and mitigating nearby affected infrastructure such as electrical lines and gas mains can minimize both public safety impacts and collateral damage such as transformer shorts.

   Example Utility faults: New York City reports instances of utility leaks and breaks, including water and gas incidents, where lack of timely and accurate data impeded emergency operations, sometimes for hours and even for days.

6. **Application: Disaster Preparedness and Response**: Earthquakes, floods, hurricanes, explosions and terrorist attacks can cause widespread damage to underground infrastructure networks. If disaster planners have comprehensive information about sensitive network elements, their interdependencies; and potential for cascading effects on other infrastructure, they can use a variety of modeling and predictive tools to identify and mitigate the most vulnerable and/or critical elements so as to minimize the extent of damage should a disaster event occur.

   Benefit: Actions that harden key infrastructure elements and enable rapid response to deal with the anticipated effects of major breakage can save billions of dollars and prevent cascading outages from impacting many thousands more people than need be the case.

Example: NYC Deep Infrastructure Group (DIG): Following the attack on the World Trade Center on 9/11/01, New York City established the Emergency Mapping and Data Center (EMDC) that included a Deep Infrastructure Group to gather information about the infrastructure networks and underground soil conditions within the disaster area. The information that was made available came in a variety of digital formats and physical media. Spatial coordinates were in a variety of projections. Drawing scales, styles and symbols were all different. In the middle of an enormous disaster, it took the City more than a week to integrate the disparate data while responders faced the threat of secondary explosions from underground freon tanks, fires from buried fuel tanks and the instability of the retaining wall (known as the bathtub) that protected the WTC site from the nearby Hudson River.

7. **Application: Smart City Technologies:** New generations of sensors and smart control valves that can be attached to underground infrastructure components are transforming the way in which infrastructure networks deliver optimal services while minimizing cost and disruption. Such technologies only contribute to these goals, however, to the extent that they accurately characterize and affect the state of that infrastructure. This requires that they be part of comprehensive and spatially accurate models of infrastructure information that include both underground and connected above ground structures.

   Benefits: Smart sensors and smart controls with associated analytic processing and feedback can optimize the performance of infrastructure networks, reducing customer costs and minimizing the waste of utility resources. Utility efficiencies help to enhance service levels and improve urban quality of life.

2.4 Initiative Scope

Subsurface and below ground utility networks: A common data model for underground infrastructure will need to represent all the components necessary to characterize that infrastructure as a whole in order to enable infrastructure data interoperability and standards formation. Such components will at a minimum include or cover:

- Infrastructure networks
  - Water
  - Sewer
  - Electric
  - Gas
  - Steam
  - Telecommunications
  - Transit
  - Any of the above that are present but inactive

- Soils, surface and other underground features
    - Surface cover and usage, e.g. street, sidewalk, building and open space characteristics
    - Hydrography and bathymetry
    - Surface elevation
    - Soil
    - Bedrock
    - Water table
    - Foundations, basements, cellars, vaults, passageways
    - Geological faults and other geological features
- Connectivity relations
    - Interdependencies between different infrastructure networks
        - Sewer connections to transit tubes
        - Electrical connections to subways
    - Supply, Transmission, Distribution and House Connections
    - Relationship to aboveground features and data standards
- Business processes/legal requirements
    - Data required to support business or legal processes around underground assets.

Other elements may exist and respondents are encouraged to identify them.

Surface and above ground utility networks: The primary purpose of this project is to develop interoperability standards for underground infrastructure data in urban environments. In doing this OGC recognizes the need to look towards developing interoperability standards as well for infrastructure networks and features that run on or above the ground. Such above-ground utility networks are present even in dense urban areas but are more often found in suburban and rural areas.

Rural and suburban areas: It is the hope that this project will initiate and facilitate a process by which infrastructure interoperability standards are developed that encompass the characteristics of all kinds of utility networks located in all types of areas. From the standpoint of urban infrastructure, this is important because the supply chains of many types of utilities involve the transmission of resources from generation plants, wells and reservoirs located outside urban areas. Additionally, having infrastructure interoperability standards that cover every kind of community will enable regional planning efforts that examine infrastructure not as isolated islands of urban use, but as interdependent parts of a regional whole.

Mobile sensors and probes: Mobile autonomous probes that can travel along the street surface or through tunnels and pipes are increasingly cost effective for both characterizing underground infrastructure and monitoring its operation in real time. These technologies, such as ground penetrating radar, are likely to have a profound influence on collection and utilization of underground infrastructure data. This RFI welcomes any information about these technologies that might be pertinent.

2.5 RFI Response Elements

The following RFI response elements have been identified as potentially relevant; responses do not need, however, to be constrained by this list:

- Existing Data Models and Software
  - Current state of art in infrastructure data standards and interoperability capabilities.
  - Implementations and applications of CityGML models as well as other information models and standards relevant to infrastructure characterization.
- Current state of city infrastructure mapping and data management
  - Referenced cities may cover a range of populations, from 100K to 10M+, as well as different levels of infrastructure density and maturity.
- Technology trends that anticipate future interoperability requirements
  - Surveying and feature delineation for existing underground infrastructure
  - Security standards
  - Smart city components such as sensors and intelligent infrastructure components
  - Big data analytics for modeling and predictive analysis
  - Autonomous platforms for infrastructure management and maintenance
- Continuity/connectedness of below and above ground assets and structures.
  - Data models for connecting above and below ground elements of a network as well as representing relationships with other important features
- Infrastructure relationships to the natural environment
  - Models for the geological, hydrological, structural, and biological context of infrastructure assets
- Combined asset and supply management data
  - Integration of data for management of the physical assets and management of services provided through the assets
- Relationships between networks,
  - Spatiotemporal and functional relationships between infrastructure networks both individually and collectively (e.g. dependencies and cascade effects).
- Workflows
  - Business and logistical processes for collection and integration of data, for example in the case of new or realigned assets
- Statutory/legal requirements
  - Impact on processes and model requirements.

3 Instructions for responding to this RFI

3.1 Who can respond

This RFI is announced to the general public. It is open to responses from any organizations with an interest in the underground infrastructure.

3.2 General terms and conditions

Responses to this RFI will be distributed to members of the organizations listed in section 1.2. Submissions will remain in the control of this group and will used for the purposes identified in this RFI. A summary of the CDS project will be made public including excerpts of some RFI responses. If your wish to submit proprietary information, contact (techdesk@opengeospatial.org) in advance of sending the response.

3.3 How to transmit a response

Send your response in electronic version to the OGC Technology Desk (techdesk@opengeospatial.org) by the submission deadline. Microsoft® Word format is preferred, however, Rich Text Format, or Adobe Portable Document Format® (PDF) are acceptable.

3.4 RFI response outline

Responses to this RFI are urged to use this outline:

1. Description of responding organization
2. Use cases for underground mapping and modeling
3. Architectures, standards and technologies
4. Implementation examples

Respondents are free to add any additional topic as they think appropriate. An organization need not respond to all topics in the outline.

3.5 Questions and clarifications

Questions and requests for clarification should be sent to techdesk@opengeospatial.org. Questions received as well as clarifications from the RFI developers will be posted publicly at the Underground Infrastructure CDS web site:
http://www.opengeospatial.org/projects/initiatives/undergroundcds

3.6 Reimbursements

The organizations issuing this RFI will not reimburse submitters for any costs incurred in connection with preparing responses to this RFI. Cost share opportunities may arise from the future phases of the project as described in the abstract of this document.

3.7 Schedule

Responses to this RFI are requested on or before March 15, 2017. At the discretion of the organizations supporting the RFI, responses may be accepted after that date, but those responses may have less effect on the CDS process.

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