A Cost Benefit Assessment of Subterranean Information Management (SIM); A Counterpart to Building Information Management (BIM) 3.15.18v5

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1.0 Introduction

In support of the Underground Infrastructure Interoperability initiative of the Open Geospatial Consortium (OGC), the purpose of this paper is to present a cost benefit assessment of efforts to standardize underground infrastructure and environment data through the development of interoperable data models. Such data standards are an essential first step in overcoming the current state of data incompatibility which creates inefficiencies for many utility related work processes. This paper is anchored by a number of studies conducted over the past twenty years whose findings quantify the benefits that are enabled by the removal of barriers to data access and interoperability; and from improvements in data quality and the use of advanced data analytics.

This paper looks at five benefit tiers. Each benefit tier has one or several foundational studies to back it up. Best would have been to conduct a rigorous analysis of infrastructure related work processes, deriving fresh metrics from surveys and interviews. However, there was no funding available for such an effort which would have taken a year or more to complete.

From a quantitative standpoint, two coefficients stand out. The U.S. National Institute of Standards and Technology in an August, 2004 issued a report entitled “Cost Analysis of Inadequate Interoperability in the U.S. Capital Facilities Industry” which conservatively calculates that inefficiencies in the interoperability of construction related data – without reference to data quality - accounts for 1.83% of total lifecycle construction costs as applied to commercial, industrial and institutional buildings. Additionally, a Purdue University Study prepared for the Federal Highway Administration, dated December, 1999, calculates that raising data quality levels (from Quality Levels C and D to Quality Levels A and B) through the use of subsurface utility engineering (SUE) results in savings of 1.9% of total construction costs.

Using the NIST and Purdue studies alone, and applying them to underground infrastructure related construction projects strongly suggests the potential for reducing utility construction and maintenance costs by 3.73%. This report goes on to identify potential saving that could result from the application of data analytics – such as extending the expected life of utility networks by identifying and reducing factors that cause premature aging. It also provides a qualitative assessment of how improvements in data interoperability, accuracy and analytics can support gains in smart city development and in disaster preparedness and response. For jurisdictions that wish to begin thinking of the total annual gains possible from all categories of benefits, a rough rule of thumb might be to **multiply by 5%** the total annual cost of utility construction and maintenance; plus foundation and basement costs of private and public construction.

At the conclusion of the report there is a simple “Do It Yourself Calculator” that can be used to develop a “ballpark” quantification of benefits, customizable for any jurisdiction.

2.0 Benefit Tier 1: Interoperability costs for Underground Infrastructure Related Projects

The first benefit tier is concerned with the costs imposed on the construction industry by deficiencies in data interoperability. Data interoperability is the capacity of information to be rapidly and seamlessly shared among all those who need it. Cost figures are based upon a study conducted by the National Institute of Standards and Technology (NIST) which was published in August, 2004. Because of the complex nature of this study, and the application of its findings from above ground construction to underground infrastructure projects, an explanation of the NIST methodology and findings follows.

2.1 "Cost Analysis of Inadequate Data Interoperability in the U.S. Capital Facilities Industry" by Michael P. Gallaher, et al, National Institute of Standards and Technology, August 2004 http://nvlpubs.nist.gov/nistpubs/gcr/2004/NIST.GCR.04-867.pdf

Overview of NIST Study Methodology and Findings

Project Lifecycle: The NIST study addresses data interoperability costs across the construction lifecycle from design and construction; to operations and maintenance – the latter covering the fifty or more years during which a structure is utilized. The NIST study focuses on the construction of buildings for commercial, institutional and industrial use. It does not specifically address construction projects and processes related to underground infrastructure networks, and to above ground buildings that serve the purposes of sourcing, generating, treating, controlling or storing utility resources such as power generation plants, electric substation, wastewater treatment plants, reservoirs, steam generation plants, pumping stations or telecommunications broadcasting and switching centers. The NIST study is particularly important because it generates a series of benefit ratios based upon extensive survey data.

Project Participants: The NIST study examines data interoperability between the following: In the design phase – architects and engineers; in the construction phase – general contractors and specialty fabricators and suppliers; and in the operations and maintenance phase – owners and facility operators. Challenges to data interoperability occur both within lifecycle phases (e.g. between architects and engineers for the design phase) and between lifecycle phases (e.g. between general contractors and operators who need as-built drawings to support maintenance operations).

Costs Incurred By Interoperability Inefficiencies: NIST identifies the following cost factors that result from data sharing and interoperability deficiencies. They include: Labor time involved in transferring, validating, re-entering, converting, duplicating and reworking data; and the expense of software to support duplicate systems and conversion operations; the labor time to operate those duplicate or redundant systems; and the expense of correcting mistakes made when the wrong architectural and engineering data is utilized particularly during the construction and operating phases.

Methodology for Documenting Interoperability Costs: Section B-1 of the NIST Study contains the survey instruments utilized to capture interoperability costs at each of the three phases of the project lifecycle and between all key players who participate in the project lifecycle tasks identified.

Modeling Interoperability Costs: As described in Section 4.3, NIST develops a "Counterfactual Scenario" which "…compares the current status of construction information management to a hypothetical scenario in which interoperability issues do not occur." NIST goes on to explain that in a counterfactual scenario all needed information is available when required and is entered into electronic systems only once after which it is available to stakeholders "instantaneously" through information systems that are interoperable and make full use of standardized tools.

What the NIST Counterfactual Scenario Does Not Include: NIST points out that that the counterfactual scenario focuses on "the timing, cost, and increased availability of currently collected information. It does not include potential benefits – or opportunity costs – of improving information accuracy and analytical techniques. These additional potential benefits will be explored in latter sections of this review.

Relevance of NIST Results to Underground Infrastructure Networks and supporting structures: This report assumes that the NIST cost estimates for interoperability deficiency costs are relevant and applicable to the segment of the construction industry that deals with infrastructure networks and their supporting structures. While some costs may be greater for commercial, institutional and industrial buildings – there are costs that are likely greater for underground infrastructure related construction.

- **Interoperability Costs Likely Greater for Commercial, Institutional and Industrial Buildings**
    - **Architectural Services**: Vertical construction projects generally employ architects to develop an overall building design before turning over plans to engineering firms to work out the specific construction plans. Generally, design services for underground utility networks and facilities do not heavily utilize architectural firms and so this particular kind of handoff is not as significant.
    - **Specialty Fabricators and Suppliers**: It is likely that during the construction phase of a project the large number of specialty trades utilized for vertical construction projects create information interoperability problems owing to variety and incompatibility of the data systems involved.

- **Interoperability Costs Likely Greater for Underground Infrastructure Networks and Support Facilities**
    - **Underground Utility Networks Require Information from other Utility Networks:** Particularly in large, dense cities as many as seven or more different types of utility networks – and often dozens or even hundreds of different utility providers - must share the space underground. Effective design, construction and operations and maintenance work for one utility must take into account the location and physical characteristics of other nearby utilities. Typically, different utilities, as they transitioned from paper to digital records, adopted non-standardized, proprietary information systems. Due to security and competitive concerns utility companies have been reluctant to share their source information. “Dig Safe” and “One Call” systems in the U.S. have helped to mitigate this problem; however, painted street markings do not represent the exchange of the highest quality data available in the fastest time possible. Inadequate and delayed information sharing with utilities can greatly increase costs at all phases of the construction lifecycle.

    - **Underground Utility Network Construction Work Requires information about the Underground Environment:** In addition to needing to know about other nearby utilities, the design of underground infrastructure projects also requires information about subsurface characteristics such as soil types, soil moisture content, the presence of caustic chemicals, water table, abandoned structures of all kinds, archeological remains underground streams, bedrock, basements, foundations, utility service connections; and pavement composition and thickness. Unknown subsurface conditions are recognized as one of the primary causes of project delays and change orders. “Geological surprises are a major reason that projects are delayed and go over budget.” (McKinsey and Company, “Imaging Construction’s Digital Future”, June 2016.) It has proved extremely challenging to bring together all this information. Within a jurisdiction there can be a number of government agencies and private firms that collect subsurface information, but access to this data is generally restricted. In addition, much of this data is paper based, or if digital, does not adhere to a common standard, making integration of data from different sources extremely challenging.

    - **Underground Utility Networks are Largely Invisible:** Deficiencies in data interoperability for buildings that are predominantly above ground are mitigated to some degree because there is the ability to gain lighted access to many building mechanical and utility areas. However, aside from widely spaced manholes and vaults, most underground infrastructure is invisible: buried beneath layers of asphalt, concrete and soil, while also entangled with other utilities. This makes the data gathering required for routine maintenance, trouble shooting, service additions and disconnects that much more difficult. In some instances, test pits need to be dug, at significant extra cost, to understand underground characteristics.

    - **Underground Utility Networks are Being Constantly Accessed:** Utilities, contractors, city agencies and others need constant access to buried underground assets for a variety of maintenance, repair, upgrade and new service activities. With an estimated 200,000 street excavations annually in NYC and more than 1,000,000 utility inputs required (Common Ground Alliance estimates 6.6 notifications required per excavation) data interoperability challenges are faced on a daily basis. With 6,000 street miles, NYC averages more than thirty excavations per mile, per year. This level of activity suggests that interoperability costs for operations and maintenance of underground infrastructure networks may be substantially more than those for above ground buildings.

- **Additional Note On Interoperability Costs Related To Underground Infrastructure:** The NIST study compiled interoperability costs oriented to above ground construction projects. What was not assessed was interoperability costs associated with the pre-design surveys of underground characteristics and conditions, and the assessment of utility location, characteristics and capacity; all essential for the design and construction of building foundations, basement mechanical layers, and connections to utility services. Had the NIST study taken these interoperability requirements into account, cost factors would certainly have been higher than they were.

Conclusion: Short of redesigning and reorienting the NIST study to measure underground infrastructure related interoperability costs, there is no certain way of knowing whether the 2004 study is fully applicable to utility construction and maintenance operations. Based upon the discussion above, we feel it is reasonable to assume that the 1.83 percent interoperability cost figure, calculated by NIST as a percent of total project costs, is applicable to both underground infrastructure networks and to above ground utility related facilities. Additionally, it is possible that the interoperability costs for the operations and maintenance phase of underground infrastructure related construction projects (e.g. The 50+ years of expected life of infrastructure network components) is considerably higher than that for the above ground portions of buildings. This is because underground infrastructure is subject to continuous assault from excavations, street vibrations, soil movement, moisture and caustic chemicals; and interaction with adjacent utilities.

2.2 Based on the NIST Analysis, Interoperability Benefits from Improved Subterranean Information Management (SIM) via Digitization, Standardization and Accessibility

Work Processes Across the 3 Phases of the Construction Lifecycle

This section takes a closer look at the specific ways by which the interoperability costs of underground infrastructure related projects can be reduced by improved digitization, standardization and accessibility. It follows the three phase construction lifecycle described in the NIST report.

2.2.1 Phase 1: Design (Architectural and Engineering Service): Estimated reduction based on NIST study of 0.135% of annual costs

- **Capital Planning**: Every utility must look at their entire network, the age and capacity of each component, in relationship to evolving threats and demands, and to opportunities presented by new technologies. This process requires the use of information covering individual utilities, but also information about other adjacent utilities.
    - **Benefit**: With information about all utilities available and capable of seamless integration, time currently spent by planners and engineers to bring together and analyze data from different utilities can be reduced, and more time can be spent on creating useful intelligence to guide capital planning in ways that increase utility efficiency.
- To support the **design of major capital construction and replacement** engineers and architects of utilities spend time accessing the records of their own and other utilities and integrating them. In some instances, staff from one utility may be permanently assigned to other utilities.
    - **Benefit**: Because all utility records will be accessible online and capable of rapid integration, staff working at the offices of other utilities can be reassigned.
- **Underground environmental conditions** must be known to properly plan for major capital improvements. Currently borings, foundation records, elevation and LiDAR data, water table, bedrock, soils and other related information is located in isolated silos, often as manual records or in non-standard data formats.
    - **Benefits**: All data related to underground environment will have been brought together, standardized and made available via easy electronic access. This can significantly reduce design time and reduce staff time associated with gathering and integrating incompatible information. It can also save the expense of duplicating data collection efforts.

2.2.2 Phase 2: Construction: Estimated reduction based on NIST study of 0.463% of annual costs

- **Streamlining information capture in the field**: As utility capital construction takes place it is important to capture as-built details about the new facilities which can differ significantly from the original engineering designs. When this information is captured at all it is often done in ways that are not compatible with existing records requiring re-entry or conversion.

  - **Benefit**: Standardized digital data capture of as built information and underground environment conditions – as well as identification of the location of other utilities that have been uncovered is done in the field in a format suitable for automatic update of central records.
  - **Benefit**: Underground infrastructure connections to structures of all kinds, generally occur at the basement level. The ability to map the connections between utility distribution networks and buildings means that underground information management (SIM) systems can interact with building infrastructure management (BIM) systems. This linkage, when seamless, offers opportunities for efficient data exchange, improved utility modeling, and the elimination of duplicate data entry, incompatible data, and information gaps.

2.2.3 Phase 3: Operations and Maintenance: The NIST study estimates a reduction 1.23% of annual O&M costs for above ground construction projects. Underground infrastructure O&M consists largely of the excavation of buried utilities for a variety of repair and service augmentation purposes.

Overview of Guiding Studies: There are a number of studies that document the work processes of routine street excavation, and their inefficiencies.

- **Common Ground Alliance (CGA) Damage Information Reporting Tool (DIRT), Analysis and Recommendations 2016, Volume 13, released August, 2017** (http://commongroundalliance.com/sites/default/files/publications/DIRT%202016%20Annual%20Report_081017_FINAL_Updated_09.20.17.pdf)
  - CGA-DIRT estimates the total number of excavation damages (strikes, accidents, errors) in the U.S. in 2016 at 379,000, while societal costs associated with underground facility damage are estimated at $1.5 billion. Costs associated with utility excavation damages (damage incidents divided by costs) is rounded to $4,000 per incident, not including the costs of property damage, evacuations, road closures, environmental impacts, lawsuits, injuries and fatalities). Page 1
  - CGA-DIRT estimates 1.76 damages per 1,000 outgoing 811 notifications to utility companies. CGA-DIRT also estimates 6.62 utility transmissions per incoming locate requests. 1.76 X 6.62 = 11.65 damages per 1000 incoming locate requests, for simplicity, rounded to 1%.
- **“What Do Utility Strikes Really Cost?” Professor Nicole Metje, etal; University of Birmingham, School of Civil Engineering, January, 2016** http://assessingtheunderworld.org/wp-content/uploads/2016/11/IBuild-Cost-of-Strikes-Report-General-Anonymised-FINAL-1.pdf

  The total cost ratio from the utility strike case studies, of indirect and social costs, compared to the direct cost of repair is 29:1. Assuming you have a utility strike incident with a direct cost of 1,000 pounds, based on the case findings, the true cost is actually 29,000 pounds. Page ii

- **Informatie Vlaanderen, "KLIP as a Response to the OGC Underground RFI", Jeff Daems.** http://www.opengeospatial.org/projects/initiatives/undergroundcds (Look for RFI response from Informatie Vlaanderen, "KLIP as a response to the OGC Underground RFI".
    - Flanders, with about 200,000 excavation requests each year, finds a "reduction of interpretation time/costs of the information by 60%" saving millions of Euros each year. Page 3
    - "KLIP regulations were adapted so that the standard time for an UNA (Utility Network Authority) to respond to a map request has been decreased from 15 to 7 working days. Furthermore, thanks to the automated processes implemented by most UNAs, almost all answers are available within one or two days after the map request submission in KLIP." Page 22
    - Netherlands addendum to Flanders Submission: In the next phase of KLIP cable and pipeline companies will send drawing instantly for placement on a KLIC viewer for presentation to excavators through a viewer. Herman Waijers, "KLIC The Netherlands Now and In The Future."

2.2.4 Assessment of Benefit Potentials for Operation and Maintenance Work Processes

- **Elimination of major current manual components of the 811 Dig Safe program including**:
  In many States, 811 processes includes a number of steps that are heavily dependent upon manual labor including the identification and notification of utilities in the vicinity of a proposed excavation, the lookup of utility information pertaining to the excavation, the transport of those records to the site of excavations, and the physical marking of the street and sidewalk to indicate where utilities are located.
    - **Benefit**: Based on a request for excavation (200,000+ annually for NYC) 811 Dig Safe staff will not need to identify affected utilities in the area of the proposed excavation since identification will be automatic taking less time and requiring fewer staff.
    - **Benefit**: With utility network information contained within a seamless digital map that can be quickly accessed, utilities will not need to manually search their records and extract details in the area of the proposed excavations. Instead, accessing this data will be automated with significant savings in time and labor.
    - **Benefit**: Because utility information can be accessed online by excavators, crews will not be required to mark utility location directly on the street. This will result in reduced labor needs and faster information turnaround time.
- **Elimination of current waiting period** between the application for an excavation permit and start of work.
    - **Benefit:** Based on Flanders, Belgium implementation their KLIP system the waiting period between application for excavation and excavation has been

reduced from 14 days to 2 days but could be done in a matter of hours largely eliminating project delays and reducing cost of idle resources.

- **Elimination of waiting period for utility and underground environment information in response to a utility breaks, outages, and malfunctions**. At the present time the process of getting utility records to the field in response to an incident can take many hours and even days. For example, there are approximately 400 watermain breaks in NYC annually. Also, the rate of accidental utility strikes and breaks may be about 1% of total excavations and number therefore about 2,000 annually. Waiting for proper records to arrive at the site of an underground incident and then working to interpret data in various media and formats can waste the time of personnel and can result in a variety of direct costs and social costs including loss of services and transportation tie ups. Failure to quickly and properly understand the underground incident (digging without a complete picture) can result in great direct physical damage such as extended flooding and greater utility damages.
    - **Benefits**: Field accessibility of standardized utility and underground environment data will reduce time wasted at incident sites before action can be taken.
    - **Benefit**: Fast action will like reduce the damages caused by a utility break and also reduce costs associated with loss of business and lawsuits.

Conclusion: For the purposes of this Cost Benefit assessment and based upon the examples above, we propose the acceptance of the NIST calculation – **1.83% of total construction costs** - as a default value to calculate the cost of data interoperability inefficiencies to the capital programs of major utilities, and to site survey, excavation, foundation and basement construction and utility connections of all construction projects.

3.0 Benefit Tier 2: Potential "Opportunity" Benefits From Improved Underground Infrastructure Digital Data Quality, Accuracy and Completeness

Beyond improving access to and interoperability of underground infrastructure data, we will explore the possibility of achieve additional layers of benefits through improvements in data quality, accuracy and completeness.

3.1 Guiding Documents with Excerpts:

- **Purdue University Study – Cost Savings On Highway Projects Utilizing Subsurface Utility Engineering (SUE)**
  https://www.fhwa.dot.gov/programadmin/pus.cfm
  "A savings of $4.62 for every $1.00 spent on Subsurface Utility Engineering (SUE) was quantified from a total of 71 projects. These projects had a combined construction value of $1 billion. The costs of obtaining Quality Level B and Quality Level A on these 71 projects were less than 0.5 percent of the total construction costs**,** and it resulted in a construction savings of 1.9 percent over traditional Quality Level C and Quality Level D data. Qualitative savings were non-measurable, but it is clear that those savings are also significant and may be many times more valuable than the quantitative savings."

- **Subsurface Utility Engineering (SUE), Federal Highway Administration**
  https://www.fhwa.dot.gov/programadmin/sueindex.cfm

- **"Proper Use of Surface Geophysical Equipment", Federal Highway Administration**
  https://www.fhwa.dot.gov/programadmin/equip.cfm

- **"How Can We Better Manage Underground Assets in Britain" Deep Dig Summary, Geovation Challenge 2016, Ordnance Survey of Great Britain.**
  "London's Heathrow airport has an abundance of underground assets – including 45,000 manholes, 115km of water mains and 130km 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 incidences due to inaccurate data by over 80% (Zeiss, 2015)." Page 2

- **Utility Mapping Service (UMS) submission to the OGC RFI, Philip Meis and Lapo Cozzutto, Document found at:**
  http://www.opengeospatial.org/projects/initiatives/undergroundcds
  "Utilities are a leading cause for construction delays, project cost overruns, and moreover are a high risk in regard to damage claims, worker health and safety, and service disruption litigation." Page 1
  The UMS/Berenice submission explores the application of SUE principles through a set of varied infrastructure projects. While many of these project have a transportation

focus, the importance of locating other utilities is apparent, and there is no reason to believe that underground utility construction projects would not benefit in the same degree by a highly accurate mapping of other nearby underground utilities, soils and surface roadways and other transportation features. Projects mentioned include NorthWestern Energy Gas Pipeline, Los Angeles World Airport (LAWA) Automated People Move, and Honolulu Light Rail (HART) Design.

- **"Imagining Construction's Digital Future" by Rajat Agarwal, Shankar Chandrasekaran and Mukund Sridhar, McKinsey and Company**
  https://www.mckinsey.com/industries/capital-projects-and-infrastructure/our-insights/imagining-constructions-digital-future
  McKinsey Quotes from "Imagining Construction's Digital Future" June, 2016

  "The construction industry is ripe for disruption. Large projects across asset classes typically take 20 percent longer to finish than scheduled and are up to 80 percent over budget."

  Among five trends that McKinsey says will shape construction and capital projects the first one on the list is "Higher-definition surveying and geolocation".

  "Geological surprises are a major reason that projects are delayed and go over budget. Discrepancies between ground conditions and early survey estimates can require costly last-minute changes to project scope and design. New techniques that integrate high-definition photography, 3-D laser scanning, and geographic information systems, enabled by recent improvements in drone and unmanned aerial vehicle (UAV) technology, can dramatically improve accuracy and speed."

3.2 Focus on the Purdue University Study: In December 1999 the Purdue University Department of Building Construction Management published a study for the Federal Highway Administration. The study reviewed cost savings from utilizing Subsurface Utility Engineering (SUE) techniques to enhance information about underground infrastructure and soils. SUE is defined as follows:

"A practice of engineering that manages the risks associated with subsurface utilities via: utility mapping at appropriate quality levels, utility coordination, utility relocation design and coordination, utility condition assessment, communication of utility data to concerned parties, utility relocation cost estimates, implementation of utility accommodation policies and utility design."

The employment of SUE principles requires raising the accuracy of utility records from Quality Levels D and C to Quality Levels B and A. The following are definitions of the different quality levels:

- Quality Level D: Information derives solely from existing records or verbal recollections
- Quality Level C: Information obtained by surveying and plotting visible above-ground utility features and by using professional judgment in correlating this information to Quality Level D information. This is the most frequent used quality level of information at construction sites.
- Quality Level B: Involves the application of appropriate surface geophysical methods, based on the use of sensors, to determine the existence and horizontal position of virtually all utilities within the project limits. Based on the American Society of Civil Engineers, surface geophysical techniques include the use of electromagnetic methods, magnetic methods and elastic wave methods.
- Quality Level A: Information obtained by actual exposure (or verification of previously exposed and surveyed utilities) of subsurface utilities, using (typically) minimally intrusive excavation equipment to determine their precise horizontal and vertical positions, as well as other utility attributes. Accuracy is set at 15mm (0.6 inches). Sensors with video capability that can travel through utility pipes can also be used.

The Purdue University Study concluded after reviewing more than seventy highway projects worth more than $1B, that for every $1 invested in SUE and raising data quality levels from D and C to B and A, benefits of $4.62 were realized. The cost of SUE was less than an average of 0.5 percent of project costs while construction savings of 1.9 percent were achieved.

3.2 SUE and the Concept of Lower Design and Construction Costs Through Higher Quality Utility Data:

The Purdue University Study provides quantitative confirmation that improved utility data yields construction savings that are achievable in the following ways:

- **Avoidance of Utility Relocations**: Unnecessary utility damages and relocations are avoided because accurate utility information is available to designers early enough in the development of a project to design around potential conflicts. This also results in a reduction in the number and cost of change orders because there are far fewer surprise conditions encountered.
- **Enhanced Safety**: Certainty about utility location can reduce instances of injury, property damage and release of product (e.g. water, gas, sewerage) into the environment.
- **Use of Advanced, Automated Construction Techniques**: When utility locations are known comprehensively and accurately, automated excavation and utility installation methods can be used with greater confidence, with the potential to significantly lower costs.

Summary: Purdue University study finds that for highway construction projects, raising the quality of utility data from levels D and C to levels B and A are associated with a 1.9% reduction in construction project costs with a ratio of cost to benefit of $1:$4.62. We are making the assumption that these levels of benefits apply generally to all underground utility related construction projects. These benefits are in addition to the benefits achieved through improved data interoperability as described in section 2.0 above.

3.3 Value of Improved Data for Reducing Utility Strikes and Accidental Breaks During Routine Excavation and Maintenance Operations

In section 2.2.3 we explained how routine excavation activities could benefit from improved data interoperability, focusing on reductions in wait time for information and reductions in work time for manual street marking operations. In this section we will add the potential to reduce strikes and accidental utility breaks that can occur during routine excavation operations.

Excavation Damages: Studies of excavation activities (see section 3.1.1) support an estimate of between 30 and 40 excavations annually per urban street mile for routine activities such as utility repairs, new utility connections and utility replacement. For New York City it is estimated that there are more than 200,000 such excavations annually. Flanders reports similar numbers. The Ordnance Survey of Great Britain believes there is an even greater density of excavations in London. The CGA-DIRT 2016 report estimates that there is approximately one instance of utility damage for every 100 excavations. Damage can occur when inaccurately located street markings or the absence of street markings result in an accidental utility strike during the excavation process. Damage can also occur when a utility line whose location is known, and which may in fact be already uncovered, is broken due to accident or inherent fragility.

Improved information timeliness, accuracy and comprehensiveness: We believe that as utility location information and information about the underground environment improves it will be possible to reduce the number of utilities damaged as a result of excavation activity.

- **Accuracy**: By improving the horizontal and vertical location of utilities, excavation crews will be better able to anticipate utility placement resulting in fewer strikes and accidents.
- **Comprehensiveness**: Due to gaps in infrastructure records, the location of some utility features are unknown resulting in utility strikes during excavations. For example: paper drawings may be misplaced, lost or damaged. The systematic discovery and digitization of missing records, and techniques to check all new excavation sites for utilities that are not recorded, should gradually eliminate this problem.
- **Underground Environment**: In addition to utility location, work crews in the field can also be sent information about the underground environment which might have an effect on excavation activities. Knowing in advance about soil conditions, moisture levels, and past problems for excavations in similar locations can improve the approach taken by work crews resulting in better safety outcomes.

Benefits from improved information: For routine excavations, the Common Ground Alliance 2016 DIRT Report notes that the average cost of a utility strike or break during an excavation is about $4,000. Studies done of Heathrow Airport and in Flanders demonstrate that superior data quality does result in a reduction in utility damages. For the purposes of this report we include benefits obtained from the use of high quality utility information for routine excavation and maintenance activities to be included within the 1.9% benefit estimated by the Purdue University Study.

4.0 Benefit Tier 3: Opportunity Benefits from Improved Data Analytics

Guiding Documents

Utility Mapping Service (UMS) and Berenice International Group submission to the OGC RFI, Philip Meis and Lapo Cozzutto, Document found at:
http://www.opengeospatial.org/projects/initiatives/undergroundcds

“Imagining Construction’s Digital Future” by Rajat Agarwal, Shankar Chandrasekaran and Mukund Sridhar, McKinsey and Company
https://www.mckinsey.com/industries/capital-projects-and-infrastructure/our-insights/imagining-constructions-digital-future

Improved access to and interoperability of all sources of underground information coupled with greater accuracy and completeness can serve as an excellent platform for analytic methods that provide insight into how various utility networks, soils, and environmental conditions -like moisture and vibration – interact. Such analysis can provide invaluable information about how to more efficiently and effectively manage operations, protect assets, and make investment decisions. This has the potential for substantial savings.

A quote from the McKinsey white paper “Imagining Construction’s Digital Future” illustrates where current digital trends are headed: “Advanced analytics helped a major London Infrastructure project save time and money when project leaders worked with data-analytics company to produce a web-based adaptive-instrumentation-and-monitoring system. The system absorbed field-sensor data, construction-progress data, and workforce and vehicle movements. Statistical analysis based on this information helped project teams detect anomalies and identify potential risks – critical information for a dense and historically sensitive city like London.” Pages 22-23

Similarly, the UMS Berenice proposal to OGC’s Underground Infrastructure RFI states the following: “The utility data collected and modeled is used to produce a risk map and perform a sensitivity analysis to help designers understand the best alignment for a new utility installation (or some other proposed design). This is a ‘laparoscopic’ procedure for underground installations, where all data are collected with a scientific procedure, and the project design can be reviewed in a controlled, proactive, predictive manner. These methods also enable use of virtual design and construction methods, machine control construction, and elimination (of) utility related contingency costs for delays, damages, claims and public disruptions.”

As these methods and technologies, driven by access to interoperable, high quality data, extend from specific project sites to entire utility networks, it is not difficult to imagine several kinds of analytics that could be employed to extend utility life and predict and prevent service breaks from occurring.

- **Match Threats To Utility Vulnerabilities**: Factors that can threaten the integrity of infrastructure networks include vibration from trucks, trains and traffic; high soil moisture content, sandy soils at risk of subsidence, the presence of caustic chemicals in the soil; electromagnetic characteristics that can hasten utility weakening; heat and cold; and instances where utility elements settle and press down against each other. The age, thickness, composition and historical behavior of infrastructure components when matched against the threats mentioned above, can lead to the mapping of utility segments at greatest risk. This would enable utility engineers to develop precision mitigation programs that would likely reduce utility breaks and extend utility life.
- **Analytic Strategies Applied To Gas Infrastructure**: Older gas mains made of cast iron can be at high risk of leaking, breaking and even exploding. The strategy described above is particularly apt for these kinds of mains. In discussions about this project, mention was made of the poorer quality of gas main information in NYC and the fact that there may be no record of the location of a number of abandoned pipelines. A first essential step is to determine those sections of the network where a combination of old mains and the presence of corrosive underground conditions can pinpoint areas that need special attention. Guided by this information, a new generation of robots are available to inspect and even repair old gas mains. See: https://www.nytimes.com/2017/12/26/nyregion/con-ed-robot.html "The (Cisbot) robot is also less expensive than the old methods of maintaining the mains," stated John Ciallella, Con Edison's section manager for gas engineering reliability. He noted that hiring ULC Robotics for work on West End Avenue in Manhattan's Upper West Side, cost $400,000. "To do the job the way such work used to be done would have cost $1.5 million to $1.8 million," he said.
- **Premature Aging of Roadways**: The longevity of street pavement, the time between needed repaving, is determined by conditions that attack pavement integrity from above and below the street surface. From above there is vehicular vibration, extremes of heat and cold, and excavation work that tears at the street surface on average thirty to forty times per mile, per year. From below, it is likely that a major threat is soil subsidence which removes support for the roadway and subjects it to greater stress. NYC DOT has expressed the wish to understand why some streets exceed the average age before repaving is necessary, and why others require repaving over much shorter periods of time. With comprehensive data and the right analytics it might be possible to identify those factors that play the greatest role in causing pavement to age prematurely and to develop strategies to mitigate those factors. Extending the life of roadways by an average of even one year could mean major budgetary savings.

  https://www.dot.state.oh.us/Divisions/Finance/GASB%2034%20Documents/PavingCostpermile.pdf http://www1.nyc.gov/office-of-the-mayor/news/513-16/mayor-de-blasio-dot-repaving-more-roads-budgeted-current-fiscal-year

- **Watermain Breaks**: Watermain Leaks and Breaks: New York City suffers about 400 watermain breaks annually. Strategic information about pipeline age, material, load, thickness, prior history of leaks combined with soils information could lead to preventive actions that reduce the number of breaks. A reduction in watermain breaks lowers emergency construction costs (DEP and DOT) and lawsuits from affected businesses and residences. The City currently pays out millions of dollars annually to settle lawsuits related to damages caused by watermain breaks.

  In a WaterWorld Magazine article entitled "Patching up the Pipes: How Smart Technologies Help Cities Prevent Leaks and Save Money" by Jesse Burst; http://www.waterworld.com/articles/print/volume-30/issue-7/editorial-features/patching-up-the-pipes-how-smart-technologies-help-cities-prevent-leaks-and-save-money.html it is reported that there are 237,600 water line breaks each year in the US costing public water utilities approximately $2.8B and averaging about $12,000 per break. Plus leaky pipes steal 7 billion gallons daily. For NYC: 400 annual water line breaks (0.17% of US total) annually X $12K = $4,800,000. Watermain breaks generally start as leaks which might be detected and mitigated using a combination of sensors and analytics.

  Also see: http://www.nyc.gov/html/dep/html/ways_to_save_water/water-distribution-system-optimization.shtml NYC has an extensive leak detection program which would be aided by better information about adjoining utility networks and an in-depth knowledge of soils.

Conclusion: Using a combination of higher quality utility and underground environment information, sensors, robotics and analytics; utility and roadway projects can realize significant benefits. We believe these kinds of benefits can be extended to the analysis of entire utility systems, their interactions, and their underground environment.

We were unable to find a study which assessed the extent to which utility life could be extended through the use of effective analytics. In Section 9.0 of this report is a Do It Yourself Benefits Calculator. Metric 4 of this benefits model suggests a 75 year life for water infrastructure and proposes, as a placeholder metric, a one year life extension due to the use of analytic techniques. We then calculate an annual benefit based on these assumptions. We hope that in the near future studies allow us to arrive at a fully fact- based benefit quantification.

5.0 Benefit Tier 4: Opportunity Benefits for Smart Cities Programs from Improved Interoperability, Quality and Analytics

5.1 Guiding Document: “Partnering To Build Smart Cities” Jurgen Laartz, Stefan Lulf, McKinsey and Company: https://www.mckinsey.com/search?q=partnering%20to%20build%20smart%20cities

Urban areas around the world are experiencing significant growth, and are increasingly competing with each other for larger shares of the global economy.

Planners and managers understand that the strategic application of new, digital technologies by cities can be a key differentiator, exerting a major influence on where jobs and companies will go and where people will want to live. This is because the use of digital technologies and the intelligence derived from them support business work process, drive down prices and can greatly improve the quality of life.

Subterranean Information Management (SIM) must now be added to other emerging digital technology systems that are revolutionizing the way we live and work. It joins Building Information Management (BIM), air and ground sensors, the Internet of Things (IoT), wearables, social media, artificial intelligence, and vehicle telemetries as technological capabilities that are transforming society while generating huge new volumes of digital data. The field of “big data analytics” has come into being to take advantage of this data by bringing combinations of data together to find valuable new knowledge and insights. The growth in the sophisticated use of these vast data resources is the driver behind the movement towards “Smart Cities.”

The Open Geospatial Consortium understands that there is enormous value in developing data standards that permit data interoperability within and between different application platforms. For example: Interoperability between SIM and BIM would enable the modeling of practically the entire built environment and its management as an integrated whole.

The contributions of Subterranean Information Management (SIM) can make to Smart Cities includes the following:

- **Better Use of Sensors and Smart Infrastructure to Detect Problems and Increase Utility Efficiencies:** Smart utility components including intelligent pipes and adjustable valves and controllers will make it possible for utilities to offer new types of services customized to the needs of consumers and which also help to conserve resources and save money. A “smart grid” approach to electric power not only shifts electric capacity to different areas depending on time of day, but also can accept inputs from small scale sources of electric generation, like the solar panels on the roof of a building.
- **Green Cities**: Many green cities strategies rely upon harnessing infrastructure networks in ways that conserve resources and enhance the environment. For example: Storm water runoff during heavy rainfall can overwhelm wastewater treatment plants and

result in raw sewerage being released into surrounding water bodies, degrading water quality. This problem can be mitigated by a variety of infrastructure related strategies such as green roofs, absorption of runoff by pavement designs that include trees and grassy areas, and by diverting storm water to basins in natural areas. Proper strategy requires accurate information about the underground environment including the absorptive capacity of soils; and a comprehensive knowledge of the sewer system so strategies can be comprehensively modeled.

- **Smart Telecommunications:** Wired and wireless networks are key to the emerging digital environment that smart cities will depend upon. It is essential that low cost, high bandwidth access to flexible and varied telecommunications services are available. These services will support SIM, BIM, IoT, autonomous vehicles and many types of consumer services. Accurate mapping of where telecom technology is located, who controls it, and details about service capacity, are essential to planning for and installing a highly efficient system that minimizes wasteful duplication and service deficiencies.

Conclusion: Subterranean Information Management is an important component of Smart City strategies. It has the potential to support innovative ways of supplying utility services, reducing prices and enabling the use of a wide variety of efficiency producing new technologies. At this point it is not possible to quantify these benefits. But we are convinced that smart utility systems based on high quality data and analytics, can significantly add to smart city initiatives, making jurisdictions where they are implemented, more competitive.

6.0 Benefit Tier 5: Qualitative Assessment of the Benefits of Emergency and Disaster Related Subterranean Information Management

How Urban Areas and Regions prepare for and respond to disaster events is a strong indication of how smart they have become.

Geospatial Information Systems are widely recognized as an essential component of disaster operations. Most of the information that relates to such events has a location component, and the response community has found that the ability to integrate data from multiple sources and to provide real time information about the impacted area is critical for establishing situational awareness. A disaster response is the ultimate test of whether the many data related systems that serve all segments of a society can work together to save lives, preserve property and restore services. State-of-the-art disaster response must now include bringing together data not only from all levels of government, but also from social media, sensor networks, structures of all kinds, and utility networks.

Utility resilience is an important component of disaster preparedness, response and recovery operations. Many of FEMAs Emergency Support Functions (ESF) have a strong relationship to utility services including water supply, electric power, transportation and telecommunications. However, experience with disaster events demonstrates that underground infrastructure information is afflicted by poor accessibility, interoperability and quality.

Emergency Incidents: The New York City Office of Emergency Management reports that during incidents involving subterranean utilities, it is often difficult to rapidly assemble and effectively utilize information from several infrastructure networks because of slow access to paper records, restrictions on sharing information, incompatible digital formats, and incompleteness and inaccuracy of some data. Consequently, effective emergency response may be delayed for hours and even days as data is assembled and integrated, sometimes as a series of paper utility drawings laid out on the hood of a truck. Such delays have resulted in greater damages and prolonged losses of service. In some instances information delays can even put lives at risk.

Disasters: A gas pipeline explosion in Flanders, Belgium is an important reason why utility mapping has advanced in Europe over the past fourteen years. Similarly, NYC has suffered two major disasters with strong infrastructure involvement: The 9/11 attack on the World Trade Center and in 2012, Hurricane Sandy. In both instances underground infrastructure was heavily damaged and resulted in heightened awareness of the importance of interoperable, comprehensive and high- quality utility data.

- **Gas Pipeline Explosion in Flanders, Belgium**: In 2004 a major pipeline exploded due to an accidental utility strike caused by nearby excavation activities which proceeded unaware of the gas pipeline. Twenty-four people died and one hundred and fifty were injured. Fourteen years later, Flanders has completed a world leading system that is based on digitizing all utility data to common standards and rapidly making the combined data available online**.** Not only is Flanders realizing major benefits because excavations take less time to review and approve, but they have significantly reduced the odds of another major disaster caused by a utility strike. https://en.wikipedia.org/wiki/Ghislenghien

- **World Trade Center 9/11**: Following the collapse of the Twin Towers pressure from the Hudson River threatened to collapse the retaining wall (known as the "bath tub" surrounding the WTC site). Also, underground fires fed by underground fuel tanks for backup generators threatened to ignite a tank filled with Freon liquid which could have resulted in the release of poisonous gas. Additionally, underground infrastructure plans for utilities, basement and foundation layers was essential for search and rescue operations and for the support of recovery and rebuilding efforts. An Emergency Mapping and Data Center was organized immediately following the attack, however it took more than two weeks before underground infrastructure data could be assembled and integrated and even then, there were information gaps.

- As **Hurricane Sandy** approached New York City, weather forecasters warned about an unprecedented storm surge risk. Although it had long been thought that storm surge posed the greatest natural threat to the City, critical infrastructure had not been fully evaluated for its ability to withstand major flooding. As the storm surge peaked, the East 13th Street electric substation was knocked out causing most of Manhattan south of 34th Street to be blacked out. There were numerous other blackouts in the NYC Metro Area. Additionally, three major hospital facilities located close to water bodies lost power and had their basements flooded, requiring the evacuation of many of their patients. Furthermore, a number of subway and vehicular tunnels connecting Manhattan to Brooklyn and Queens were flooded, the salt water causing extensive damages that are still being repaired.

The capabilities mentioned below illustrate the benefits that would be made possible if underground infrastructure data were fully digitized, standardized and made interoperable, accurate and complete.

- **Vulnerability Analysis:** Having complete utility network data available for analysis and modeling would make it possible to accurately anticipate the vulnerabilities of key infrastructure components to a variety of possible threats, and to anticipate the cascading effects that might result from the failure of strategic utility nodes. This would enable the emergency management community to prioritize strategic utility features for hardening. A recent example is the loss of electric power on the Island of Puerto Rico as a result of Hurricane Maria. A vulnerable electric power transmission network stretching across the entire island was largely destroyed by the Hurricane cutting electric services to almost all residents, businesses and hospitals. Many months after Maria's September

20th landfall, hundreds of thousands of customers remained without reliable power. A rigorous assessment of Puerto Rico's electric power infrastructure prior to Maria would likely have identified vulnerabilities and strategic measures that might have reduced destruction and resulted in a reduction inoutages and repair costs. https://www.theatlantic.com/science/archive/2017/10/what-happened-in-puerto-rico-a-timeline-of-hurricane-maria/541956/

- **Rapid Access** to many sources of accurate information, the swift integration of that information and the continuous development of analytic products to serve the response community is essential to an effective disaster response. Integrated utility information is an essential component of this data environment and would help to provide better situational awareness (SA) and allow the development and maintenance of a common operating picture (COP) to inform decision makers and response teams in the field making repairs and providing services to the public.

It is difficult to quantify with any reliability, the potential value of improved underground infrastructure interoperability, accessibility, accuracy and completeness, to mitigate the effects of a major disaster or a smaller scale emergency situation. However, we feel confident in saying the having this data on hand will certainly reduce the risks associated with almost any infrastructure related event. If properly used to take strategic mitigation action to harden critical infrastructure, many millions of dollars could be saved should a major disaster strike.

It is estimated that Hurricane Sandy did $19B in damage to New York City. At least $5 billion in damages was a direct result of impacts on utility infrastructure. In retrospect, it seems clear that much of infrastructure damage could have been anticipated, and perhaps mitigated well in advance of Sandy with a modest investment of resources.

7.0 Cost Assessment

The costs involved in creating a comprehensive information environment that enables interoperability, improved data quality and completeness, and more effective analytics are difficult to quantify because there are practically no examples to draw upon. For the moment, we will simply list those cost elements that are most obvious. Where we do have hints of cost metrics, we will present them.

- **Modifying the Information Environment of Each Utility:** It will be necessary for each organization holding underground utility and environment information, to map its current data holdings to the standardized interoperable data models developed by the Open Geospatial Consortium. This standardized data must then be placed on a platform that allows sharing with other utilities and data sources under carefully designed operational rules and in conformance with appropriate security requirements.
- **Digitizing Paper Records:** For those utilities that still rely on paper records, it will be necessary, within a reasonable period of time, to convert those records to digital format. Using a very rough estimate, this could cost several thousand dollars per utility mile. Costs depend upon the ability to apply scanning and interpretive software to facilitate the process.
- **Converting CADD Drawings:** For those utilities whose records are in CADD format, it will be necessary to extract necessary linework and attributes and place them in into GIS environment that conforms to or can interact with OGC utility data models and standards. Such conversion could cost one thousand dollars per utility mile but could be considerably lower if software tools are able do a significant part of the conversion work automatically.
- **Re-engineering of 811 Dig Safe Procedures:** Currently, most if not all States in the U.S. requires the establishment of an excavation clearinghouse that receives requests for excavation, notifies utilities with service lines in the vicinity of the excavation, and requires them to send out a crew to mark the location on the pavement. This has proven to reduce strikes and other kinds of utility damage, but not eliminate them. This process takes time and involves a number of workers. To enable full interoperability would require 811 procedures to be re-engineered so that excavation requests and responding utility location would happen quickly if not instantaneously. It would likely require the design and implementation of a new application architecture and the retraining and redeployment of staff. **Example**: Flanders, Belgium has undergone a conversion to standards based digital underground utility information. Each operating utility in the region was given about seven years to convert their records. It would be useful to obtain information about the costs involved in making this transition.

- **Improved Data Quality:** Creating standardized digital records from current data holdings makes data interoperability easier without improving data quality or completeness. While this by itself provides important benefits, more can be done. The Purdue University Study finds that the application of Subsurface Utility Engineering (SUE), to raise data quality from D and C levels to B and A levels can substantially reduce construction costs. Achieving these levels of data completeness and accuracy requires thorough research into utility records and various means of surveying utility locations using technologies such as surface sensors that can "look through" pavement, and subsurface sensors that can be threaded through utility pipes or lowered through holes in the ground. While costs are significant they can be lowered by steadily improving technologies and techniques. **Example:** Recently, the City of Chicago has initiated a pilot project where 3D digital cameras are used to take photos of the pipes exposed during excavation activities. By deriving accurate utility data from ongoing excavations – perhaps between thirty to forty excavations per street mile, per year - Chicago may be developing cost effective data capture techniques that incrementally improves data quality over time.
- **Data Maintenance:** To continue to retain its value, high quality underground utility data must be properly maintained. This requires putting in place a robust data maintenance operation with properly trained technicians, appropriate equipment, and work processes that continually document and bring changes in the field to the attention of the data maintenance operation in near real time. It would not be unreasonable to estimate that data maintenance costs, as a percent of the cost expended to put higher quality data in place, might be in the vicinity of 20% annually.
- **Improved Analytic Methods:** The ability to develop strategies that extend the life of utilities and that identify utility segments at highest risk of failure, depend upon the ability to apply analytic techniques to high quality data, which includes data from sensors that can persistently monitor utility conditions. New methods, software and sensor technology must be researched, developed and evaluated. The costs associated with this approach may be high, but could be mitigated if urban jurisdictions facing similar challenges could share costs.

Conclusion

The costs associated with improved utility data interoperability, quality, completeness and analytics are considerable. However, if we can accept a level of benefit that equals four or five percent of all underground related construction costs, which for larger urban areas can well exceed $1B annually, we are dealing with a level of payback that would make significant investment in utility data well worthwhile. Additional benefits from Smart Cities initiatives and from improved disaster prepared would be a bonus.

8.0 Conclusions

There is a substantial body of documented findings that demonstrate improved digitization, standardization, interoperability, accessibility, accuracy, currency, and completeness of subterranean infrastructure and environment information, when coupled with geospatially oriented analytic techniques, can reduce construction costs and yield substantial benefits. To achieve these objects will be expensive but we believe costs will be substantially outweighed by benefits. One of the ways by which costs can be kept down is for the international community to move forward together, sharing R&D, methods and strategies.

An important step forward in achieving these goals has been the recent release, by the Open Geospatial Consortium, of draft, interoperable underground infrastructure data models. The data models, developed by an international team led by OGC, is an example of how collaboration can produce results at a reasonable cost. Such models, when refined and adopted, will be able to support utility data interoperability and set the stage for improved data quality and completeness, and for the deployment of powerful analytic tools that depend upon high quality data.

A number of cities and nations around the world already understand the urgency of getting underground information right and have major initiatives to deal with this issue. Cities and nations include:

- Chicago, U.S.
- Denmark
- Flanders, Belgium
- London, U.K.
- New York City, U.S.
- Netherlands
- Singapore
- Sydney, Australia

With the data models in hand and, we hope, some assistance from this cost benefit analysis, lead cities will continue to move ahead and more cities will join this initiative and take part in the collaboration.

We are now on the verge of a revolution in underground data interoperability and quality which promises not only significant day to day operational benefits; but also new initiatives that protect urban areas from disasters, and enable them to take better advantage of new smart city initiatives.

9.0 Do It Yourself Benefits Calculator: Selected Metrics

We hope the following set of formulas can be used or adapted so that they provide a ballpark estimate of the savings possible by implementing a program that seeks to improve the interoperability and quality of underground infrastructure data; and provide analytics that provide insights into how to extend the life of infrastructure components.

9.1 Improved Availability and Interoperability of Existing Data: Fictional City of Icon

Because every municipality is different, for the sake of simplicity, we will develop a benefits model for a fictional City, at a scale that can be projected to a jurisdiction of almost any size. Local governments wishing to utilize this benefits model must substitute their own values for the ones given for the fictional City of Icon.

<u>City Facts and Figures to be Customized for Each Case Study:</u>

City of Icon: Note that facts and figures in bold are used in the Metrics to follow

- Population: 1,000,000
- Area: 300 Square Miles
- Miles of Roadway: 3,000
- Typical Miles for Citywide Utility Network: 3,000 miles for water, sewer, gas, electric and telecommunications
- Municipal water and sewer capital budget: $150M annually
- Municipal water and sewer PS and OTPS budget devoted to infrastructure maintenance: $25M annually.
- Total annual value of utility capital construction projects related to underground Infrastructure: $450M (includes utility capital projects, and major emergency repair operations)
- Total annual expenditure for construction projects by non-utility builders: $3.0B (includes commercial, office, residential and industrial facilities that are predominantly above ground)
- Percent of Annual expenditure of construction projects by non-utility builders devoted to foundations, basements and utility connections: 5% or $150M.
- Routine excavations: 50,000 annually (for service outages, upgrades, repairs, new service connections)
- Average cost of a routine excavation: $1,000
- Total annual cost of routine excavation: $50M
- Average cost of a utility strike or accident: $4,000
- Number of work days to fully process excavation requests and mark streets: 5 (With optimal data interoperability, time is reduced to one day or less)
- Number personnel supporting 811 Safe Dig: 5 FTE, $50,000 average salary fully loaded
- Estimated damage incidents during routine excavation: 1% of 50,000, or 500
- Annual number of water main breaks: 50

- Expected average life of water infrastructure: 75 years
- Number of watermain breaks: 50 annually

Study Derived Defaults which can be Modified To Reflect Local Conditions

- Percent of total construction costs, including annual maintenance costs, attributed to data interoperability: 1.83% Source: NIST Report
- Percent reduction in Construction Costs enabled by accurate and complete data: 1.9% Source: FWHA/Purdue University Report
- Reduced construction costs per $1 invested in data improvement: $4.62 Source: FWHA/Purdue University Report
- Percent of excavations where breaks or strikes occur: 1% CGA DIRT 2016 Report
- Cost of average excavation break or strike: $4,000 Source: CGA DIRT 2016 Report
- Average cost of watermain break: $12,000 Source: WaterWorks

Placeholder Numbers Requiring Local Specificity

- Cost of daily delay in starting routine excavation due to inefficient interoperability: $100
- Annual salaries of typical workers, fully loaded: $50,000
- Year extension to the life of water infrastructure due to improved data and analytics: 1 year (75 to 76 years). Annual reduction in capital expenditures: 1.3%

9.2 Utility Related Construction Projects

- **Metric 1:** Reduced data interoperability costs for underground infrastructure capital projects based on NIST calculations applied to water and sewer infrastructure construction and maintenance operations.
    - (Municipal *water and sewer annual capital budget)* + (Municipal *water and sewer annual PS and OTPS budget devoted to infrastructure maintenance*) X (1.83%) = estimated potential cost savings
      ($150M + $25M) X 1.83% = $3.2M (City of Icon, water and sewer utilities only)
    - Extend to other utilities as information is available. (For very rough estimate take example above and multiply by 3X to include street pavement, gas, electric and telecommunications networks: = **$9.6M**) Includes increased construction efficiencies due to data compatibility, reduced time to provide excavators and contractors with utility information, and reduced staff time for manual processing of requests and data delivery.

9.3 Opportunity Savings For Improved Data Quality and Completeness

- **Metric 2:** Reduced time delays and costs associated with utility information that is incomplete and of low quality.

  - (*total annual value of utility capital construction projects) + (total annual costs of routine excavations)* X (1.9% - estimated percent reduction of costs due to improved data) = total annual cost savings
    - **($450M + $50M) X 1.9% = $8.6M (City of Icon)**

9.4 Opportunity for Savings for Non-Utility Routine Construction Projects (buildings)

- **Metric 3:** Based on improved data interoperability and data quality, reduced costs for that portion of standard construction projects that is directly impacted by utilities and subsurface environment conditions including site surveys, excavation, foundation and basement construction, and utility connections to building mechanical systems.
  - (Total annual capital spending for non-utility construction projects) X (Percent of projects directly impacted by utilities and subsurface conditions) X 3.73% = Expected value of cost reductions
  - **$3.0B X 5% X 3.73% = $5.6 M (City of Icon)**

9.5 Opportunity Savings for Improved Subsurface Data Analytics

- **Metric 4:** Value of extended utility life due to smarter maintenance and replacement strategies: Extending expected life by one years over a seventy-five year cycle can yield more than a 1% savings in capital costs over that period of time. The example below pertains to the life of water and sewer infrastructure and potential benefits include reduced costs due to fewer watermain breaks and sewer backups.
  - (*Extended pipeline life – standard pipeline life*) X (*Annual municipal water and sewer capital budget/Extended pipeline life)* = annual savings due to one year of extended life
    (76 years – 75 years) X $125M /76 years = $1.6M (City of Icon, water and sewer only)
  - Extend to other Utilities as Information is Available. (For very rough estimate take example above and multiple by 3X to also include gas, telecommunications, electric, street pavement networks: **=$4.8M**)

Do It Yourself Benefits Calculator Summary

Adding up estimated benefits ($9.6M + $8.6M + 5.6M + $4.8M) shows that the City of Icon has the potential to realize about **$28.6M annually** in benefits, comprised of time reductions, lower construction costs and money saved. These benefits would be shared among municipal and private utilities, contractors, property owners and managers and the public. Moreover, difficult to quantify benefits related to smart cities and greater resilience against disasters, would also be realized through improved infrastructure data interoperability, completeness and accuracy.

10.0 Optional Benefit Metrics: The focused benefits below have been built into the larger benefit categories described in section 9.0 above. They are broken out here to provide guidance in performing more itemized benefit calculations. However, they do require valid data inputs – which are often difficult to obtain.

Benefit Type: Improved Data Interoperability for Routine Excavations

- **Reduced Time To Markup and Excavation:** Reduced time spent due to current utility excavation notification system if that system is not digital and directly accessible
    - (*Number of days from excavation request to street marking*) – (*expected digital data delivery time*) X (*cost of daily delay*) X (*total number annual excavations*) = Expected annual value of time savings
        - **Model example: (5 days – 1 day) X $100 X 50,000 = $20.0M (City of Icon)**
- **Saved Personnel Time Now Spent Managing Data:** Reduced personnel time spent on supporting the 811 Dig Safe back office research and field marking program
    - (*Number of personnel supporting 811 Safe Dig*) X (*average annual salary*) = Expected annual value of personnel services that can be allocated to other tasks
        - **Model example: 5 X $50,000 = $250,000 (City of Iron)**

Benefit Type: Analytics for Reduced Watermain Breaks

- **Reduced Number of Spontaneously Occurring Watermain Breaks:** Using analytics to identify infrastructure candidates most likely to suffer service interruptions and breaks, and using that knowledge to reduce the number of incidents: For example – In NYC it may be possible to reduce the approximately 400 watermain breaks annually by better understanding where those breaks are most likely to happen and increasing inspection, repair and replacement activities.
    - (Average cost of watermain break) X (annual number of watermain breaks) X (*expectation of reduced incidents as a percent of total incidents*) = expected annual savings
        - **Model example: $12,000 X 50 X 10% = $60,000 (City of Icon watermain breaks)**