Mapping the Underworld: A Step-Change in the Approach to Utility Location and Designation

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ABSTRACT

Trenchless technologies (TT), unlike open cut trenching, offer the potential to install, maintain and refurbish buried utilities without the need to close long stretches of carriageway. Recent studies indicate that carbon emissions associated with trenchless installations are far smaller, and trenchless installations are more sustainable, than trenching. Yet utility companies, and their contractors, routinely shun trenchless technologies due to the perceived risk of damaging previously undetected third party assets. Mapping the Underworld (MTU) seeks to create a multi-sensor tool, and a new philosophical approach to underground mapping, to mitigate such risks and facilitate the routine adoption of TT. The novel approach is now being developed through the proof of concept stage towards field trials and the results of these proving trials form the basis of this paper. Moreover such street works, like all construction, repair, renewal and maintenance projects, must be reviewed in terms of a sustainability assessment framework to explore their real costs and benefits to the society on behalf of which, as ultimate ‘users’ of the facilities, the works are being carried out. This paper seeks to integrate the findings of a highly multi-disciplinary technology-based project with a wider research programme on the context of effective and efficient working in the streets. The lessons drawn from this programme of research extend to all aspects of pipeline engineering.

INTRODUCTION

Modern living, which affords higher standards in quality of life and increased life expectancy for the majority of the populace within the UK than experienced in previous eras, is underpinned by the fruition of human endeavour in numerous sectors including agriculture, engineering, medicine, manufacture, the sciences, etc. However, in conjunction with these advances, that
make modern living possible, the importance of the successful management, maintenance and connection of utilities networks must not be underestimated. Denial of potable water, power, gas and telecommunications, and loss of efficient removal of human effluent, would rapidly result in the breakdown in modern living, as occurred with the breakdown in control of potable and foul water systems in Zimbabwe resulting in the cholera outbreak in 2008 (BBC, 2008). Thus, utilities are considered essential services without which society cannot live: supply of potable water and disposal of waste is essential for health; while provision of gas, electricity, fibre optic cables and street lighting are considered fundamental services.

These utilities are mostly supplied through pipes and cables buried beneath the ground, and are often located within the highway boundary. As such, the location of these utilities affect nearly every project that takes place within publicly owned streets. Firstly, they need to be repaired and maintained to ensure a regular supply of essential services to customers. Secondly, with urban populations predicted to increase, both within the UK and globally, by 2050 (DESA, 2007), demand on existing utility networks is likely to increase and installation of additional sections of network will be required. Thirdly, whenever work is carried out within the highway boundary, it is necessary to consider what hazards lie beneath the road surface (HSE, 2001), and one of the first stages of design often involves the collection of network records from utility companies operating in a particular area, so that the buried hazards can be avoided. Furthermore, the pipes and cables providing the conduits for the supply of the services have a finite engineering lifespan and will require replacing; the length of the networks buried below the carriageway can make this renewal process very slow, for example operational water pipes can still be found in London that date back to the Victorian era: 1837-1901.

Access to the utilities below the carriageway is still dominated by open-cut methods of construction. Trenching into the carriageway damages the fabric of the road, reducing its engineering life, and can damage the buried utilities. In the UK it has been estimated that these ‘utility streetworks’ cost £1.5 billion per year in direct construction costs (McMahon et al. 2006) and the same study estimates that damage caused to 3rd party utilities costs £150 million per year. Open cut construction methods dominate streetworks as, although alternative methods of construction exist (such as trenchless technologies), the shallow underground space within urban environments is typically highly congested by utility networks buried in a wide variety of altered natural soils and fills. These pipelines and cables do not necessarily follow the straight path between access points that may be depicted in utility records drawings as any utility traverses obstacles encountered during installation. Locating and working on a specific utility within such a potentially complex environment increases the risk of damaging the target utility or third party assets. This makes trenching desirable as the utilities can be located, and steps taken to prevent damage, as excavation proceeds. A number of trenchless technologies available to the contractor are considered ‘blind’ as the ability to locate obstacles within the path of the technology is often limited, at best, and this increases the risks associated with third party utility damage. This is particularly true for trenchless technologies that excavate or displace the ground: microtunnelling, horizontal directional drilling, pipe splitting, pipe bursting, etc. Whilst research is being undertaken to incorporate sensors into the trenchless technologies to provide
look-ahead capabilities, such as Ground Penetrating Radar (GPR) within horizontal directional drilling cutting tools (Manacorda and Miniati, 2010), these techniques are still limited in their ability to ‘see’ through the ground. Conventional geophysical techniques can be used to survey a site prior construction, and if these techniques could locate all buried utilities on the site, then trenchless technologies could be used with more confidence. However, detecting all utilities in all soil conditions likely to be encountered below the carriageway is currently considered impossible. A study (Ashdown, 2001) of remote geophysical utility detection of buried utilities on a control site, where the locations of the pipes and cables were known, illustrated the problem. An 80% location rate, at best, was returned in the study. Whilst this study was undertaken in 2001, and technology has undoubtedly moved on since then thus improving likely detection rates, consistently detecting 100% of the buried utilities for all but the simplest of configurations in ideal ground conditions is likely to still be unachievable.

Whilst the damage to the road network is undesirable, it is not the most noticeable consequence of streetworks. Congestion resulting from closed or infringed lanes due to streetworks is a pet hate of the British populace, is commonly derided in the media and has been the subject of legislation by the UK Parliament (the Traffic Management Act, etc.). Congestion results in a number of undesirable consequences, for example delays caused to road users and trade lost to local business to name but two, which result in significant costs to the UK economy; McMahon et al (2006) suggest these ‘indirect costs’ cost the UK economy £5.5 billion per year. Open cut construction methods have additional negative connotations associated with them. Congestion resulting from lane closures can result in increased levels of traffic on alternative routes, often using minor roads not designed for such levels of traffic. This results in the development of congestion on roads that are unaffected directly by the construction project; can result in increased journey distances for commuters; and increased traffic levels on minor roads can reduce the engineering life of the road, necessitating remedial construction work to ensure the road remains suitable for use. Increased journey distances result in increased consumption of fuel and hence an increase in carbon emissions. Carbon emissions are also considered to be higher with open cut methods when compared to trenchless techniques, largely due to the quantities of material removed from the road when exposing the desired utility and the materials transported to the site to reinstate the road (Rogers et al., 2009).

It is in this setting that the Mapping the Underworld (MTU) research initiative was devised. MTU is an initiative that aims to research and develop the tools necessary to facilitate a sea-change in the approach taken to streetworks associated with utility network management and repair.

**MAPPING THE UNDERWORLD: EMBRACING A SUSTAINABLE APPROACH TO STREETWORKS**

The MTU initiative arose from the perceived need, by a group of practitioners within the UK gas and water industries, for change within the streetworks practices. MTU aims to research and develop the tools necessary to promote sustainable streetworks, for example by minimising lane
occupation, undertaking night surveys and utilising trenchless technologies (Figure 1). The factors limiting the adoption of trenchless technologies as the standard suite of installation methods, replacing open-cut methods in streetworks, and the establishment of sustainable working practices are complex, and the variety of research projects undertaken under the auspices of the MTU initiative reflect this fact. The majority of the MTU research projects focus on researching and developing the tools required to locate, accurately position and electronically record the data relating to the utilities buried beneath the carriageway. However, research is also being undertaken to develop a sustainability tool to assess streetworks.

![Figure 1. Mapping the Underworld Timeline. (Published in ASTT's Trenchless International, Reproduced with Permission)](image)

**ASSESSING THE SUSTAINABILITY OF STREETWORKS**

The research undertaken in this project illustrates that utility streetworks is a complicated area, in which the utility providers are privatised and are responsible both to their shareholders and at the same time to their customers. This can result in conflict and does not always allow the utility providers to carry out work in a more sustainable way. Several different options may be available to carry out utility streetworks, but not all of these alternatives are considered each time work needs to be carried out in the street, and the works are assessed mainly in terms of direct economic costs. For example, if more accurate information is obtained during the design stage of a project, buried utilities can be located more accurately, and there is less chance of damage being caused during the works, less chance that the works will overrun, less redesign required and therefore fewer change orders. However, the costs of the works are not the only impact. In addition to these economic impacts there are many different social (such as road user delays and trade lost to local business) and environmental impacts (such as noise, dust and carbon emissions).
It has become apparent that current utility streetworks’ assessments focus on the direct costs of the work. No holistic approach was found that includes the three areas of impact referred to as the ‘three pillars of sustainability’: economy, society and environment. The environmental and economic aspects of this approach are easier to quantify than the social elements, but considering any one of the three pillars in isolation presents problems because it is difficult to advance one element of sustainability without having an impact, and often a negative effect, on the other two (Parkin et al. 2003). Elghali et al. (2008) refer to this as ‘Pareto optimality’. Although it should be noted that several sustainability assessment tools exist in other areas, for example SpeAR® (Braithwaite, 2007), SpeAR® adapted for geotechnical projects (Holt et al., 2010) and CEEQUAL (Campbell-Lendrum and Ferris, 2008), none of these tools was found to be directly suitable for assessing utility streetworks. Therefore, the focus of this research is on the development of a Sustainability Assessment Tool (SAT) that will visually demonstrate, in a novel way, how ‘sustainable’ a particular design option is, so that different options can be compared. The SAT for the utility streetworks will be applied to various case studies, provided by parties sympathetic to the aims of the MTU initiative, that exemplify best practice in the UK and overseas. For example one case study will investigate the performance of an initiative between a local highway authority and various utility companies. Maintenance schemes of the utility companies were synergised; in doing so the total combined estimated project time was reduced from 32 weeks to 10 weeks. The SAT will consider the outcomes of the project (increased planning costs from cross-party cooperation, reduced disruption to local traffic, potential for reduction in carbon emissions, etc.), to determine what practices might be of value to the wider utility community when undertaking streetworks.

**LOCATING BURIED UTILITIES WITHOUT THE NEED FOR EXCAVATION**

A number of research projects have been undertaken under MTU to create the tools necessary to allow the adoption of trenchless technologies in streetworks, including: the development of resonant RFID tags, which may be incorporated into newly installed pipes, or retrofitted to the surface of existing buried utilities, to improve the chances of detection using GPR (Hao, et al., 2008); surveying techniques that allow for the accurate positioning of the buried utilities, even in built up environments where certain surveying technique can struggle to operate efficiently; and the development of a framework for the combination of data from the utility companies to create a single utility location database (Beck et al., 2007). In addition to these research initiatives, several discrete research projects are underway that aim to investigate the impact of the ground, both on the physical structure of the utilities, and to further the understanding of the relationships between geotechnical properties and geophysical properties of various types of ground in various conditions. These newly instigated projects were devised to feed into another MTU research project: the development of a Multi-Sensor Platform. The Multi-Sensor device project aims to research and develop a surveying tool that can be deployed in the carriageway in an attempt to increase the detection rate of utilities. It is contended by the research team that deploying one or more sensor(s), in isolation or in parallel,
on a site without reference to any other source of available information regarding the site is likely to lead to failure to locate all utilities in all but the simplest layouts and when buried in ideal ground conditions. Therefore, it is the aim of the Multi-Sensor Platform project to research not only the geophysical sensing technologies mounted on the platform, but the means to incorporate the information in existing utility records into the data fusion exercise along with the means to optimise the deployment of the sensing technologies on site by understanding the detrimental impact the ground conditions will have on them. It is the latter research strand of the Multi-Sensor Platform project that the newly commenced suite of research projects on the influence of the ground will feed into.

Four sensing technologies are being researched and developed for the multi-sensor platform (Metje et al., 2007): GPR, low frequency electromagnetic fields (LFEM), passive magnetic fields (PMF) and vibro-acoustics. It has been established that these sensing technologies complement one another, and are suited to different ground conditions, thus increasing the likelihood of utility detection. GPR is being developed to operate as a surface sensor mounted on the platform (to operate in the traditional ‘look down’ mode) and as an in-pipe sensor that can operate below the platform. Using the two variations of the GPR sensing technology in combination permits the traditional ‘look-down’ approach to be complemented by a ‘look-out’ system (if the transmitter and receiver are deployed in-pipe) and a ‘look through’ approach (if the transmitter and receiver are mounted on the platform and in-pipe respectively, or vice versa). It is believed that utilising these three deployment strategies with GPR will increase its effective operational depth, thus increasing the probability of detecting utilities at depths considered to be beyond the capability of traditional GPR. Advances in ‘look-down’ GPR are being achieved using orthogonal-frequency division multiplexing, since theoretical modelling suggests this approach could markedly improve detection rates (Zhang et al., 2010).

The LFEM sensing technology induces a current through the ground and uses capacitive coupling to detect anomalies within the created field. By synergising anomaly data with positional data, it is possible to detect the buried utilities. The PMF sensing technology utilises a configuration of 27 passive search coils to detect the magnetic field associated with operational power cables, thus allowing the position of the cable to be determined. The PMF sensing technology also has the potential to detect metal utilities that experience induced currents due to the proximity of operational power cables. The vibro-acoustic sensing technology utilises the compression and shear waves generated by an exciter to detect the buried utilities. The exciter may be applied directly to water filled pipes (Muggleton and Brennan, 2008), or directly on the ground, with surface-mounted geophones being deployed to receive the ground-borne waves.

The MTU Multi-Sensor Platform project commenced in 2009 and is scheduled to be completed in December 2012. The majority of the sensing technologies used in this project have been developed from first principles, and testing of the sensing technologies moved from laboratory conditions to a test site in late 2010. The outcomes of feasibility testing of the sensing technologies have proven encouraging (Royal et al., submitted). As the testing regime for the multi-sensor platform proceeds, the resultant data will be fused with utility records for the test sites to develop procedures to create probability maps for the location of the utilities on site.
The development of this process will act as a feedback system, with the utility records providing a guide as to what should be expected to be found on site (although this is not seen as exclusive), and when the datasets are fused errors within the utility records can be identified and rectified. Thus the process, when fully researched and developed, has the potential not only to increase the probability of detection, but also to improve the utility record resource for future surveys. The ground conditions in which the utilities are buried are known to impact upon the ability of geophysical sensing technologies to detect and locate them. A knowledge-based system (KBS) is being developed that can be used to take ground conditions into account and thus aid in the optimisation process for the deployment of the multi-sensor platform on site. The KBS is based upon databases that describe soil properties (such as those held for the whole of the UK by the British Geological Survey), although the parameters held on the databases tend to comprise geotechnical properties rather than geophysical properties. Therefore research is being undertaken to further the understanding of the relationship between geotechnical and geophysical properties for various ground conditions. This understanding underpins the KBS. In addition, research is being undertaken to determine how the weather in the changing seasons affects the geophysical properties of various types of ground. The KBS is being designed so that it can incorporate input directly from those with expert knowledge regarding a site so to further enhance the outputs. By combining the knowledge of the ground conditions from the KBS and the existing records data with the surveying process, it is expected that the probability of detecting all utilities buried on a site will increase markedly.

SUMMARY

The continued reliance on open-cut methods for utility installation and maintenance results in damage being inflicted on the road network and third party utilities, as well as disrupting society’s functions. These practices cost the UK economy billions of pounds each year and are considered unsustainable. MTU is a research initiative that aims to research and develop the tools required to promote more sustainable practices, based on the use of trenchless technologies, within the carriageway when undertaking streetworks. MTU is currently investigating the impact of street working methods by applying sustainability tools, developed for the project. The outcomes of this study should define good working practices that promote more sustainable construction. Furthermore, adopting a philosophy of sustainable construction within streetworks has the potential to move the industry away from the practice of only considering the methods that result in the lowest direct cost to those that are most cost affected when considering the long-term costs borne by society, the environment and the economy. MTU is also focusing on the research and development of a geophysical sensing platform, comprising four sensing technologies, that can be deployed to locate the buried utilities without the need for excavation. The deployment of the multi-sensor platform will be optimised using information from the KBS and the resultant data will be fused with the existing utility records to increase the probability of detecting all buried utilities on site. It is expected that the successful
development of the prototype multi-sensor platform will result in the ability to survey a site, using the platform, prior to the use of trenchless technology, safe in the knowledge that the location of the utilities has been identified and the probability of damaging them with the chosen trenchless technology is remote.

REFERENCES


