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Sustainable utility placement via Multi-Utility Tunnels

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ABSTRACT

Due to the adoption of short-term planning cycles and the requirement for lowest initial construction costs, the conventional method for utility installation and maintenance in the UK is via open-cut. When taking a long-term sustainability perspective there is a growing body of evidence which indicates that this method is socially disruptive, environmentally damaging and significantly more expensive, i.e. unsustainable. One long-term solution to this problem could be the adoption of Multi-Utility Tunnels (MUTs); a tunnel that co-locates more than one utility underground facilitating their subsequent repair and renewal while eliminating the need for continuous surface excavation. Unfortunately considerably higher short-term direct costs remain a significant barrier to adoption of MUTs. However, there is a lack of research to show where the economic tipping point between the two methods occurs and how it might be influenced by utility type, pipe number (i.e. density), pipe diameter, number of excavation and reinstatement (E&R) procedures avoided, location (i.e. undeveloped, suburban and urban areas), and the choice of MUT being adopted (i.e. flush-fitting, shallow and deep).

This paper aims to fulfil this research need by investigating the effect of these influences on the economic viability of various types of MUTs. The results indicate that MUTs can provide a more economically sustainable method of utility placement in all three local contexts, with the tipping points occurring where street works are likely more frequent and/or where utility density is high.

1. Introduction

For the last 200 years open-cut excavation (i.e. trenching) has been the most widely adopted solution for placing utilities below ground in the UK (Rogers and Hunt, 2006). This solution might be considered economically appropriate over a century ago for the installation of potable mains water networks and wastewater networks below ground; there were no alternatives available other than full-scale, man-entry tunnelling, and, with only these pipe networks being located below ground, future disruptions would have been assumed minimal. Allied to this, the ground surface in undeveloped, suburban and urban areas was primarily unpaved and considerably less dense than today. Moreover plentiful labour and construction materials existed while social and environmental costs were less well-defined, and either ignored or simply not considered important enough to offset the health and other social benefits of clean water and sewerage provision.

In 2012 open-cut remains the most widely adopted solution for utility placement by practitioners and yet various alternative solutions exist, such as trenchless technologies and Multi-Utility Tunnels (MUTs) (Canto-Perello and Curiel-Esparza, 2003; Curiel-Esparza and Canto-Perello, 2005; Ludovic et al., 2004). Moreover open-cut, as an engineering method, has seen little change in its fundamental approach since the early days, the primary improvements being mechanization of the excavation and reinstatement processes, mechanical support of the walls of deep excavations, and significant improvement to pipe material quality. These benefits would have been most helpful were it not for the fact that the local contexts have changed out of all recognition: the overlying surface transport (road, pedestrian or cycle) infrastructures are more sophisticated structurally and susceptible to damage by excavation, there are many more utility types now installed below ground (e.g. stormwater drainage, gas, LV and HV electricity cables, telecommunications cables, street lighting cables), and in the not too distant future, as urban centres grow, significantly more utility types could be prevalent (e.g. non-potable water networks, Pneumatic Waste Collection – PWC, Combined Heat and Power pipelines – CHPs, district heating/cooling, hydrogen; see Hunt et al., 2011). In addition there is growing awareness that future competition for use of underground space (e.g. waste storage, resource extraction, transport and people movement, and living space) is increasing at an accelerated rate (Jefferson et al., 2006; Bobylev, 2009; Parker, 2004; Evans et al., 2009; Sterling et al., 2012). Allied to this ground surfaces are now predominantly paved or built over both in suburban and urban areas (and even in rural areas, where green verges exist, utility services are commonly buried beneath paved roads) leading to significantly greater cost requirements, in terms of: asset location Costello et al.

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(2007); excavation and reinstatement for utility placement; maintenance; repair and renewal; and decommissioning. In addition the Brundtland (1987) report has made engineers significantly more aware that everything they do, including utility placement, needs to take into account current and future costs related to a much broader spectrum than direct economic costs alone (i.e. indirect economic costs, and costs to society and the environment).

As more costs are being recognised for utility placement (e.g. traffic disruption, deleterious environmental effects, health and safety hazards, premature deterioration of paved surfaces, and major risks of damage to adjacent infrastructure, see Tighe et al., 2002) there is a strengthening argument against open-cut being the predominant form of pipe installation and renewal. For example, a significant driver in placing electricity cables within bored tunnels in London, UK was to avoid disturbance claims for repeated excavation and reinstatement procedures. However, if the benefits of reducing environmental and social impacts (through the adoption of MUTs) are to be nationally recognised they need to be fully quantified/qualified and offset against the extra monetary costs associated with building and operating them. Notwithstanding this requirement, they need to be included within utility and road costing schemes. One option would be to include the value of habitat, social amenities, landscape and other 'external' factors directly within 'cost-benefit' equations (POST, 1997). However it has been suggested that alternative 'cost-effectiveness' appraisals may be required; whereby decisions are based upon schemes achieving predetermined objectives (economic, social and environmental) for least marginal cost (POST, 1997). Whatever the route taken, the first requirement must be to define more clearly each sustainability cost for open-cut utility placement (i.e. direct and indirect economic, social and environmental) and within this context to describe all sustainability advantages and disadvantages offered through MUTs (Sections 2 and 3). The next stage would be to quantify/qualify and compare each cost for open-cut utility placement with MUTs (in various situations) in order to build a compelling sustainability argument for or against the adoption of MUTs. In Section 4 we develop a methodology for such a purpose, illustrated through the use of costs which reflect best current real world decisions (i.e. direct economic costs – labour, material and equipment). These direct economic costs are considered using three important stages of open-cut construction (i.e. excavation, pipe placement and renewal) in three locations (undeveloped, suburban and urban areas) and are compared to the direct economic costs of installing three different types of MUT (i.e. flush-fitting, shallow and deep). Future research will look toward adopting this same methodology for the remaining sustainability costs described herein. It is shown that even in the absence of social and environmental costs, which are assumed essential for wider uptake of underground solutions, such as tunnelling (POST, 1997), there is an economic case for deploying certain types of MUT's in certain situations.

2. Sustainability costs for open-cut utility placement

A growing body of research suggests that the total cost for open-cut utility placement should go beyond economic costs alone (e.g. Iseley and Tanwani, 1990; Chapman et al., 2003; Najafi and Kim, 2004; Rogers and Hunt, 2006; Jung and Sinha, 2007; Woodroffe and Ariaratnam, 2008; Ormsby, 2009). For example, Iseley and Tanwani (1990) and Woodroffe and Ariaratnam (2008) suggest that total costs (TC) should be considered as the summation of Direct, Indirect and Social costs whereas Jung and Sinha (2007) expressed TC as the summation of the direct costs (e.g. earthworks, restoration, overheads, material, labour, equipment), Environmental costs (e.g. noise and air pollution), Social costs (e.g. traffic delays and loss of business income) and other factors (e.g. safety, productivity and structural behaviour). Ormsby (2009) assumed TC to be divided into Direct, Indirect and External costs (i.e. Economic, Social and Environmental), where external economic costs included two factors (i.e. loss of property value due to noise and loss of business income; these being considered as social costs within the other studies. In line with the work of Chapman et al. (2003) and Rogers and Hunt (2006), this study suggests that the total sustainability costs should consist of three distinct pillars of sustainability:

$$C_{\text{SUSTAINABILITY}} = C_{\text{ECONOMIC(DIRECT+INDIRECT)}} + C_{\text{SOCIAL}} + C_{\text{ENVIRONMENTAL}} \tag{1}$$

However this study includes also the time element, which is crucial within the overall decision-making and construction process. The development timeline framework, as shown in Fig. 1, builds upon the work of Hunt et al. (2008a,b) and Lombardi et al. (2011) and provides a visual representation for mapping decisions, impacts and costs (i.e. $C_{\text{SUSTAINABILITY}}$) over time (working from the top left to bottom right). The arrows highlighted in bold show the focus of the numerical analysis performed in Section 4. The stages of the utility construction process (1 – Pre-Construction, 2 – Construction, and 3 – Post-Construction) are in line with that reported by Najafi and Kim (2004). Iseley and Tanwani (1990) previously assigned a fourth stage to this process (4 – Decommissioning and Renewal) and this has been included as a broader aspect of Stage 3. Stages 1 and 2 incorporate decisions and $C_{\text{SUSTAINABILITY}}$ over the short-term (i.e. days to years), whereas Stage 3 considers impacts which may last significantly beyond the lifetime of the asset (i.e. 50 or even 100 years). These costs may be comparable or considerably higher than the contract value (Ormsby, 2009). A broader discussion related to each pillar of sustainability shown in Fig. 1 is given in Sections 2.1-2.3.

2.1. Economic costs

Pre-construction costs can be considerable and include *ground investigations* and *survey work* required before the physical construction of the utility takes place. As an integral part of this stage, *asset location* can attract large costs due to limitations associated with soil type, utility type and depth (Sterling, 2000; Thomas et al., 2008). Uncertainty here can increase the risk of unplanned events/construction activities, hence the contractor requires protection (e.g. *insurance*) against expensive *legal claims* (Stein and Drewniok, 1998). Whilst design decisions (e.g. *open-cut versus trenchless versus MUT*) will impact significantly upon life cycle costs including social and environmental (Iseley and Tanwani, 1990) for the project, they are rarely considered in bid preparation for utility projects (Ormsby, 2009). The primary costing here is $C_{\text{ECONOMIC(DIRECT)}}$, traditionally measured in £/m (Podevin, 1998 McKim, 1997) or £/m^3 (in order to normalise for the fact that utility operations can be of varying size). Najafi and Kim (2004) suggest that $C_{\text{ECONOMIC(INDIRECT)}}$, examples of which are shown in Fig. 1, is approximately 15% of $C_{\text{ECONOMIC(DIRECT)}}$, whereas actual construction costs (e.g. *materials*, *labour and equipment*; McKim, 1997), which require double handling of soil and reinstatement of surfaces (Fig. 1), amount to approximately 70% of $C_{\text{ECONOMIC(DIRECT AND INDIRECT)}}$. This is in broad agreement with Jung and Sinha (2007) who reported the following cost breakdown: 21% – earthworks; 30% – pipe laying; 21% – restoration; and 28% – other costs (e.g. *office overheads, traffic control measures* and *temporary utilities*).

$C_{\text{ECONOMIC(DIRECT AND INDIRECT)}}$ can vary considerably between projects (Ormsby, 2009) due to the influence of specific local factors: speed of construction (Najafi, 2005); utility type (i.e. diameter and material); and depth of excavation (Mohring, 1987; Chapman et al., 2003). With respect to the last of these influences deeper excavations may require *dewatering and shoring* (e.g. sheet piling) as opposed to *sloping work* (Najafi and Kim, 2004) and large-scale