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Causes, impacts and costs of strikes on buried utility assets

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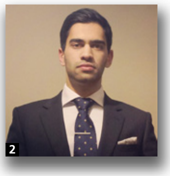


Preventing accidental damage to buried utilities is a key area that the civil engineering and construction industry is attempting to make progress on. In addition to the health and safety consequences of operatives striking buried cables or pipes, there are numerous other impacts that can occur as a result of the damage. Many organisations collect data on utility strikes and incidents, but these are not shared across the industry. The research reported in this paper is based on unprecedented access to statistics from nine organisations, which provided a total of 3348 incidents to determine any patterns. The key results were that damage to telecommunications or electric cables was the most common; the frequency of incidents peaked between 09:00 and 12:00 on working days; hand tools were the most common excavation tool involved in utility strikes, closely followed by mechanical excavators; and rules not followed contributed to half of the incidents for one organisation. Furthermore, a definitive list of the impacts and costs associated with utility strikes is presented. Repair costs, calculated in the form of an average damage repair cost per utility, have been quantified as electricity £970, gas £485, telecommunications £400, fibre-optic £2800 and water £300–980.

1. Introduction

One common feature in almost all construction projects is the need to carry out excavations or earthworks. Coupled with the fact that the vast majority of the UK's utilities (gas, water, sewer, electric, telecoms) are located underground, these activities bring with them the principal risk of hitting and damaging this buried infrastructure. This is a risk that remains ever present, regardless of the type of excavation tool used. It is also exacerbated by a number of challenges, ranging from inadequate knowledge of what lies under the ground to the use of inappropriate working methods, time, resources and commercial pressures.

Contractors, clients and utility companies record the occurrence of utility strike incidents (also known as service strikes or hits) in a variety of different ways as part of their health and safety reporting procedures. However, there is a limited analysis of these data and the review and comparison of any differences and similarities across the industry. Liaising with nine industry partners, the statistics below were collected for utility strike incidents or near-misses that they have recorded

- date
- time
- service type
- equipment (e.g. excavator, shovel, breaker)
- impacts, and repair work required.

The consequences of utility strikes include not only the direct damage to infrastructure and/or injuries to nearby workers and the public, but also a wider impact on the consumers of the damaged utility and the resultant disruption caused. Examples of these impacts include highway closures for repairs, downtime for businesses and homes, environmental damage, and requirement of emergency resources. Some assessment of the costs of streetworks has been carried out. McMahon *et al.* (2006) estimate that the societal cost could be circa £5·5 billion a year; however, it is not known what proportion of this cost is the specific result of utility strikes. It is argued that these 'real', 'indirect', or 'economic' costs are given limited consideration when planning mitigation strategies to deal with the hazard of buried utilities on projects. The total cost is also underreported when reviewing an incident (Bernold, 2003) and is often masked by the direct cost of repair borne by the contractor or utility provider. A classic example is a utility strike incident at a major UK airport, which led to the runways being closed for a number of hours, contributing to major delays and disruption, yet the incident cost was reported as only a few thousand pounds (repair cost only).

This paper, for the first time in the UK, focuses on analysing historic utility strike data/incidents across a variety of civil engineering sectors and from different companies. It further assesses the direct and indirect costs of these strikes and, where possible, quantifies these.

2. Background

An estimated 1·5 million holes are dug in the ground every year by the utility industry alone to repair and upgrade buried infrastructure (McMahon *et al.*, 2006). This figure is significant without even taking into account all the other excavation carried out for construction projects around the country.

According to Barhale (2006), most utility strikes happen as a result of one or a combination of the following reasons

- inadequate or poor planning
- rushing to complete work
- lack of information, or inaccurate information (i.e. utility plans)
- poor excavation techniques
- lack of care around services
- limited or improper use of instruments, such as cable avoidance tools (CAT)
- plant items (such as excavators and drilling machines) can also be a major culprit due to the lack of fine control and visibility that the driver has.

From a statistical perspective, much of the above corresponds with research that has been carried out in the USA and Canada by the Common Ground Alliance (CGA, 2012). The CGA is a collective of stakeholders with an interest in preventing damage to utilities and comprises over 1600 individual members and 250 member organisations, including contractors, utility firms, regulators and insurers (CGA, 2013). It publishes an annual report of the statistics it holds on utility strike incidents for that year. Figure 1 shows the distribution of reasons behind recorded events of utility damage that occurred in North America in 2011. Forty-one percent of these (of a total of 207 779 incidents) were down to insufficient excavation practices. However, in the absence of a CGA equivalent in the UK, there still is a lack of unified data analysis in the UK.

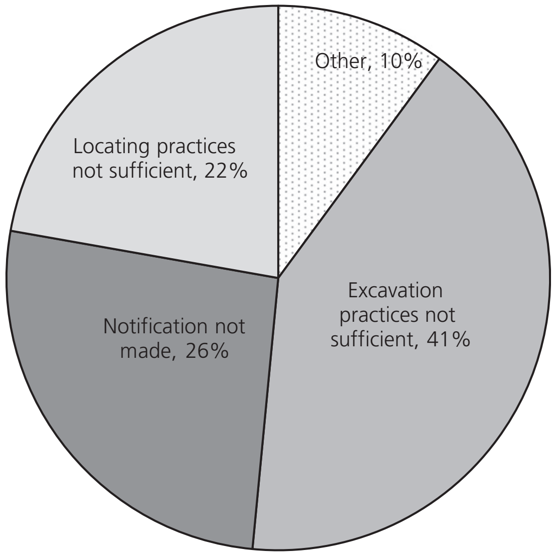

Figure 1. USA utility strike root causes (data from CGA, 2012)

2.1 Impacts of utility strikes

It should be understood that many different definitions of 'direct' and 'indirect' impacts can be found in the literature, depending on the context. For the purposes of this section, the following definitions shall be used.

- Direct cost/impact: the cost incurred to rectify the incident. Typically this will be the cost of emergency response and repairing the damage, but could also include the impact of injuries to personnel and delays to the construction project.
- Economic cost/impact: any other cost or impact that occurs as a result of the incident. In various pieces of literature (Bernold, 2003; Sanghvi, 1982) this has also been referred to as the indirect cost, the real cost, or the societal cost.

2.1.1 Direct and indirect impacts

According to HSE (2014) there are approximately 12 deaths and 600 serious injuries every year from contact with electricity cables alone. Table 1 presents a summary of direct and health, safety and environmental impacts of striking different types of utilities. Electricity cables and gas pipelines present the prime risk of fatalities and injuries.

These direct impacts are relatively easy to measure as they are direct charges which can be traced for a specific incident. In contrast, the indirect impacts resulting in the disruption to the consumers of the utility are less easy to quantify. Firstly, it is important to determine what impacts are included as indirect

Utility	Impacts of strike
Electricity cables	Electrocution
	Explosions
	Flames
	Fires
Gas pipes	Gas explosions
	Unnoticed leaks from small punctures
	Injuries from inhalation of gas
Water and sewer pipes	Flooding
	Contamination of water
	Environmental damage from sewage flooding
	Spread of disease or contamination from raw sewage
	Water ingress into other pipelines
Telecoms cables	No direct health and safety impacts but fibre optic cables highly expensive to repair
Other pipelines	Environmental damage from leakage of oils and petrochemicals
	Injuries from skin contact with volatile liquids

Table 1. Direct health and safety impacts of utility strikes (adapted from HSE, 2014)

impacts. According to Bernold (2003) consequences that could occur from service interruptions include

(*a*) loss of production
(*b*) damage to equipment and machinery
(*c*) cost of restarting
(*d*) deploying emergency back-ups to maintain service (e.g. banking systems)
(*e*) commerce (i.e. communications)
(*f*) disruption of household activities.

From McMahon *et al.* (2006) it is argued that the cost of traffic delays as a result of street closures for repair works is also a significant factor. Hayes (2012) points out the potential cost of a loss in brand image for a utility provider faced with irate customers (even though the loss of service may not be its fault). These costs are difficult to estimate, as the people affected by the incident are not the people or companies who pay for the incident. Furthermore, Sanghvi (1982) states that the actual cost of any service interruptions are dependent on

(*a*) time of occurrence (i.e. middle of the night as opposed to peak business hours)
(*b*) duration of service interruption
(*c*) magnitude of service lost (e.g. kilowatt hours)
(*d*) frequency of interruption (high frequency will mean that consumers are more likely to have back-up sources)
(*e*) area affected (i.e. urban as opposed to rural, or industrial as opposed to residential)
(*f*) warning time (likely to be zero in the event of an accidental strike)

3. Analysis of patterns in utility strike occurrence

Initially, the data were analysed with respect to the following criteria.

- Type of services hit: Crummie (2006) indicates, for example, that operatives may take less care around telecoms cables because they are perceived to be non-hazardous compared to gas or electricity.
- Month, day and time of incidents.
- Excavation tool used.
- Root cause given.
- Behavioural aspects and training: the qualitative data collected were particularly useful in this respect for comparing training procedures and policies implemented by different companies.
- Variation of the above between different companies and sectors.

Table 2 indicates the data which were used for this analysis. In total 3348 incidents were reviewed.

It was apparent from the data that each company captures and records utility strike incident details in different ways. Some record extensive information including the date, time, type of utility and type of equipment, whereas others capture incidents in a more general manner. This is challenging if the UK civil engineering industry wants to know trends and to identify the causes in order to ultimately reduce these. The Utility Strikes Avoidance Group (USAG, 2013) has a recommended method

Company	Sector/type	Time period	No. of incidents	Date	Time	Tool	Utility type	Costs
Contractor A	Major civil engineering contractor	January–October 2013	126	✓	✗	✓	✓	✗
Contractor B	Utilities contractor	January–December 2012	1045	✓	✓	✓	✓	✗
Contractor D	Infrastructure services contractor	January 2012–February 2014	411	✓	✓	✓	✓	✓
Contractor E	Utilities contractor	April 2012–March 2013	1194	✗	✗	✗	✓	✓
Client A	Transport authority	April 2011–June 2013	50	✓	✗	✓	✓	✗
Client B	Aviation client	2002–2012	170	✓	✓	✓	✓	✗
Utility A	Utility firm (telecoms)	2013	606	✗	✗	✗	✗	✓
Utility B	Utility firm (water)	2010–2013	585	✓	✗	✓	✓	✓

Table 2. Comparative overview of data received

of recording incidents and it would be beneficial for each company's own investigative purposes if this recommendation was implemented. Another limitation of the data is that not all strikes for the time period given may have been recorded. As indicated by Crummie (2006), if operatives are able to repair straightforward damage on site, they may not feel compelled to log details of the incident.

Figure 2 shows a break-down of the different utility types damaged. From Figure 2 it is clear that telecom and electric were the most damaged utilities. Initially it was thought that the high percentage of telecoms strikes might be a result of the perceived low hazard to health and the fact that there are over 2 million kilometres of buried telecoms cables in the UK (McMahon *et al.*, 2006). However, when considering that the electric cable strike rate is only slightly less at 27%, and with a length of 482 000 km in the UK (McMahon *et al.*, 2006), this argument does not hold. Figure 2 also shows the same break-down for North America based on 207 779 incidents recorded in 2011. The telecoms strikes are similar to the UK data, but in contrast, there is a significant difference in gas pipe strikes (38% in the USA compared to 17% in the UK) and electricity cable strikes (7% in the USA as opposed to 27% in the UK). Although figures for network lengths are not readily available, this difference is assumed to be the result of North America having a far more extensive buried gas network and more electricity overhead cables than the UK.

A comparison of the breakdown of strikes between the different companies is shown in Figure 3. Electricity incidents were consistently high, whereas telecom incidents showed more variability between the companies. The percentage distribution of gas strikes was the most consistent between the companies in the range of 10–20% of all incidents. It should be noted that Figure 3 shows percentages, which are susceptible to being skewed by a small sample size. For example, client A appears to have a disproportionately high percentage of incidents in the 'other' category. In actuality this is based on 14 (of a total of

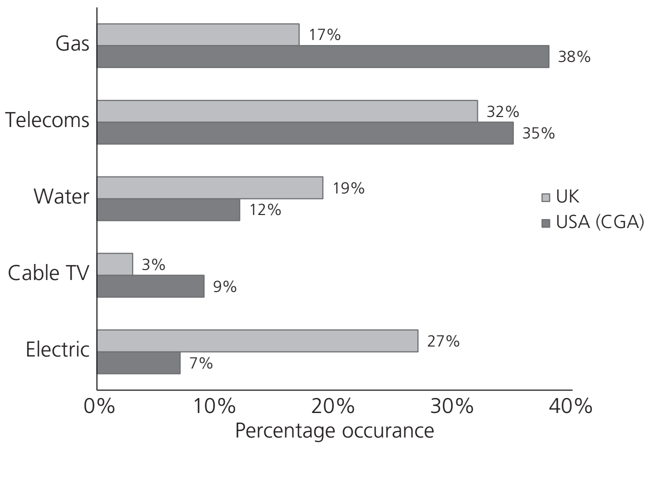

Figure 2. Percentage of all utility strikes by utility affected for the UK 3348 incidents and USA (CGA data, 208 000 incidents)

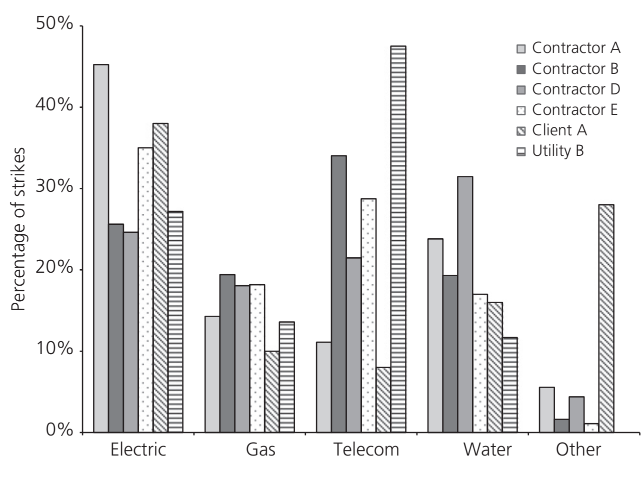

Figure 3. Percentage of strikes per utility for each company

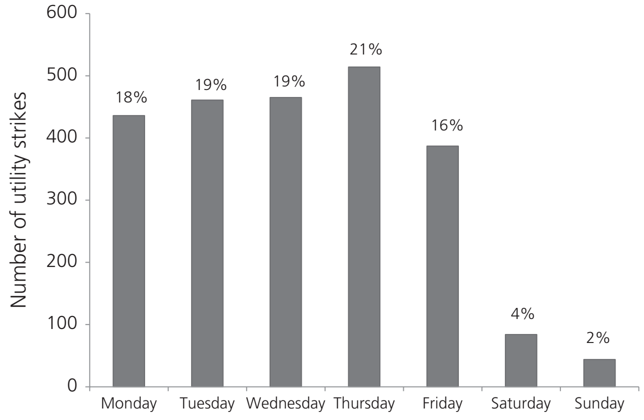

Figure 4. Number of utility strikes by day of the week (total 2391)

50) incidents for which the utility type information was not available.

There were a total 2391 incidents for which the day and month information was available. Figure 4 shows the distribution of these incidents by day of the week. The strike rates are consistent throughout the working week. The slight reduction on Fridays is most likely due to it being a typically shorter working day on construction sites.

Another question was whether the time of day makes a difference. A total of 1458 incidents were available for this analysis and are shown in Figure 5. A small number of incidents occurred outside the hours shown, but have been omitted from the graph for clarity. There appears to be a peak in incidents from 9·00 a.m. to 12·00 midday, before declining steadily towards the end of the working day. This is in line with previous

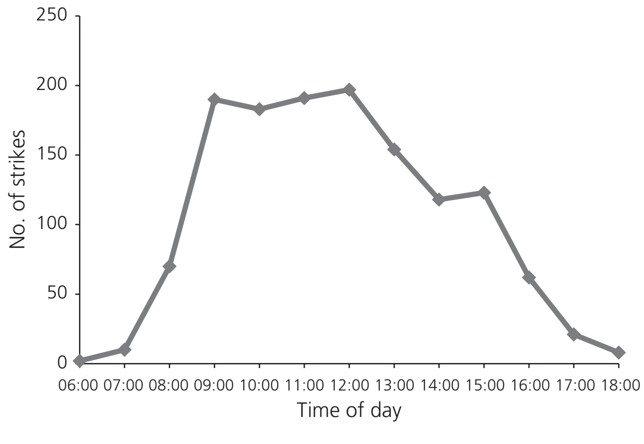

Figure 5. Number of strikes by hour (1458 incidents)

findings by Crossland (S. Crossland, 'Analysis of utility strike rates as part of Balfour Beatty's Zero Harm journey, Internal data analysis', personal communication, 2013).

One problem with the data presented so far is related to normalisation, where the data are presented as a function of either number of hours worked, number of projects or turnover. Currently, as mentioned previously, there is no unified reporting procedure for all organisations with identical data collected. During the research it became apparent that very few organisations record their data as a function of these parameters. Only contractor E provided data as a function of hours worked for one of its divisions for the period of February 2012 to January 2014 (Figure 6). The amount of hours worked generally increased from October 2012, whereas the number of utility strikes declined or remained constant. This shows that there is no particular correlation between the two factors for contractor E, but it should be noted that this was a relatively small sample set.

Having reviewed the utility strike patterns for the utility type, day in the week, hours in the day and hours worked, it is also important to determine if there is a particular tool that is used when utilities are struck. In order to assess the excavation tool used, the text comment 'descriptions' presented with each incident was reviewed. Typically these comments are provided by the operative or site manager reporting the incident to their company. The excavation equipment used was discernible for 1836 incidents, the distribution of which is illustrated in Figure 7. The pattern is largely similar to the overall figures, although telecoms strikes show a disproportionate number caused by 'breakers' and 'other tools'. This may indicate that a higher proportion of telecoms cables are embedded in concrete or tarmac. The hypothesis is further reinforced by the fact that 50% of the 'other tools' category for telecoms consists of consaws, which are used for cutting surface tarmac/concrete on roads.

An explanation of each tool type is provided below

- breaker: handheld or machine-mounted percussion hammers for breaking concrete or tarmac
- large excavator: tracked excavating machines above 10 t
- mini digger: smaller excavators up to 10 t, generally used for low-level excavations and working in tight areas such as footpaths
- hand tools: manual tools usually utilised for small jobs and trial excavations to expose utilities before excavating with other machinery; the category includes shovels, spades, grafts, picks and bars – note: picks and bars are banned by some (e.g. contractor B)
- Other tools: vacuum excavators, drills, grab lorries, consaws and roadsaws.

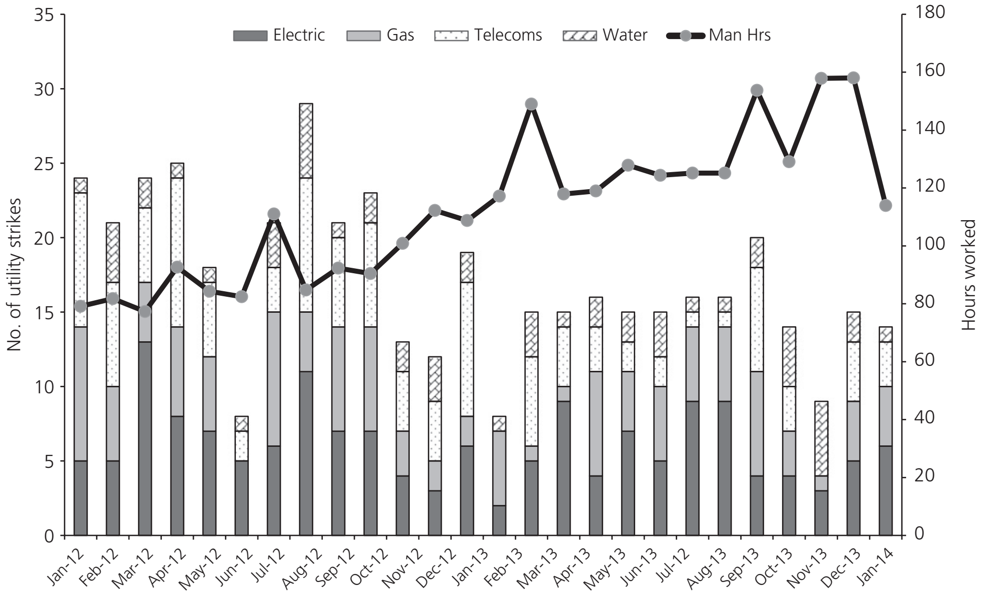

Figure 6. Utility strikes compared to man hours for a division of contractor E

Over 35% of the incidents were attributed to hand tools. This is troubling given that one of the primary reasons for using hand tools over mechanical excavators is to allow more care to be taken around buried services. The use of hand tools close to any buried asset is also in line with requirements according to HSG47 (HSE, 2014). Thus, it raises concerns about operative behaviours and practices, which can also be seen in Figure 8 indicating that 80% of incidents are caused by errors or rules not followed. The number of incidents relating to breakers (256, 14%) shows that dealing with utilities embedded in concrete or tarmac is an ongoing issue that is difficult to mitigate.

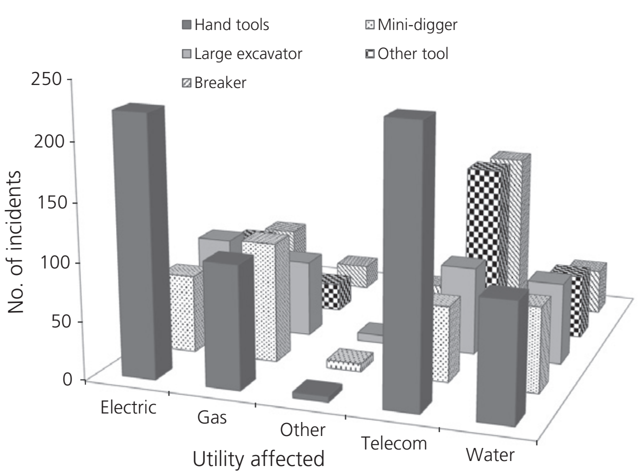

Figure 7. Number of strikes per tool categorised by utility

Comparatively, the vast majority of utility strikes in North America are caused by excavators, with hand tools accounting for less than 15–20% of incidents (CGA, 2012). For the project data, the total percentage of incidents between the two mechanical excavator types (large and mini) amounted to 33%.

4. Root cause

The data so far have not revealed any clear patterns of when utility strikes occur and thus have not revealed any potential root causes for the incidents, although the fact that many strikes in the UK occur using hand tools is revealing. In contrast to North America, where companies submit their data to the CGA including root causes, these are seldom captured in the UK data, although individual organisations may well do a specific analysis on individual incidents. The CGA classifies the following root causes, which are then broken down further to provide more detail:

- excavation practices not sufficient
- locating practices not sufficient
- miscellaneous root cause
- notification not made
- notification practices not sufficient.

For example, in 2011 it found that 41% of incidents were caused by insufficient excavation practices (CGA, 2012).

In the UK only client B provided information on root causes, differentiating between (*a*) untraceable, (*b*) abandoned,

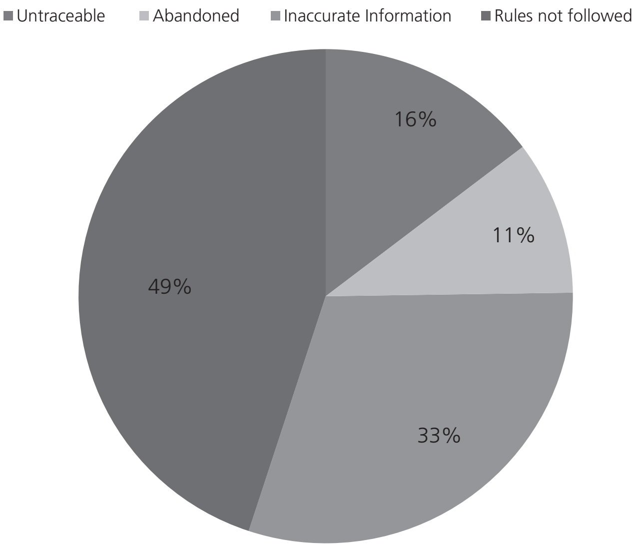

Figure 8. Reasons for causing utility strikes for client B based on 157 incidents between 2002 and 2012

(*c*) inaccurate information and (*d*) errors/rules not followed. Figure 8 shows the results for 157 incidents recorded between 2002 and 2012, indicating that causes (*c*) and (*d*) account for over 80% of the reasons why a utility is struck, with nearly 50% down to errors or rules not followed.

Additionally, the incident descriptions were analysed in more detail as a small number of comments described whether the area had been scanned for utilities prior to excavation or, whether utility plans had been reviewed. This has been summarised as follows.

- Out of 255 incidents where pre-excavation CAT scans were carried out, 52% detected the utility before the strike and 48% failed to detect the utility.
- Out of 187 incidents that indicated reviewing utility plans/drawings before excavation, 48% were on plans and 52% were not shown on the plans.
- Of the 89 that were on plans, 16% indicated that the location shown was accurate and 84% stated that the location of the utility struck was inaccurately plotted.

It is noted that USAG is currently working on providing an equivalent CGA report for the UK.

5. Behavioural issues and training

Most of the organisations who contributed data to this research have seen annual declines in the number of utility strikes over the last 5–6 years. However, the analysis also highlighted that rules not followed and errors caused a significant proportion of the utility strikes despite many organisations having ‘zero harm’ or ‘zero accidents’ initiatives. The data suggested, for example, that for over 50% of utility strikes using hand tools the utility was detected using a CAT scan prior to excavation. This indicates that behavioural training needs to be addressed in order to improve the safety performance. Figure 9 shows how the safety performance of a company can be improved including three key aspects: engineering, systems and human factors. Figure 9 also suggests that as each of these aspects is addressed individually over time, the improvement in safety performance plateaus. This indicates that it is not sufficient to only focus on one aspect to make a real difference.

Much effort has been placed on in recent years to improve safety by addressing the engineering and systems aspects through company-wide process and procedures, training, raising awareness, advances in technology and the recently published BSI PAS128 standard (BSI, 2014). However, the industry is still in the infancy of addressing human factors and changing people’s behaviours. This can be achieved through exceptional safety performance and, for example, by ensuring work gangs are proud of their own record and look out for each other. Crummie (2006) made a start in investigating the behavioural factors involved with utility damage, but it is argued that further research is needed to further assess this across the industry.

6. Assessment of costs

It has often been said that to value the buried infrastructure and any damage to it, the real costs of utility strikes or incidents have to be assessed which go beyond the direct costs of the repair of the damaged utility. The true costs of service and utility damage are unknown by most companies (Cummins, 2012). Therefore, the research attempted to assess the costs, where possible, but also to show the wider or indirect costs that need to be quantified to fully assess the real costs.

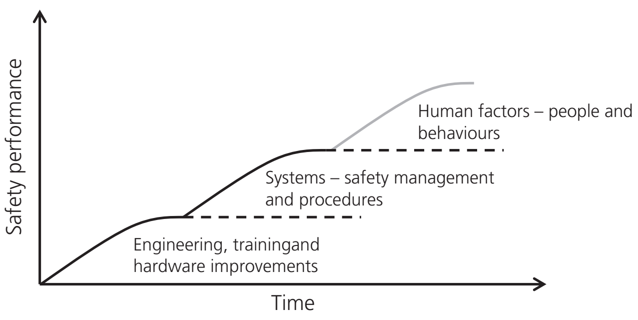

Figure 9. Three-stage improvement of an organisation’s safety over time

Type	Incident total	Claims total	Paid value: £	Average paid value: £	Highest claim: £
Electric	842	447	433 057·93	969	6240·00
Gas	378	192	93 058·00	485	554·88
Water	533	168	52 964·44	315	971·44
Telecoms	676	167	68 243·24	409	1814·94
Sewer/drain	4	1	£983·40	983	983·40
Cable TV	66	3	£1064·36	355	529·94
Totals	2499	978	£649 371·37	3516	N/A

Table 3. Utility strike claims incurred by utility B's contractors and contractor E

Table 3 shows the costs of utility repair for the different utility types based on claims made by third parties incurred by utility contractors B and E. This information is often captured for insurance purposes. Electricity cable strikes were the highest value claims – with a couple of the most expensive repairs exceeding £6000. Claims are typically handled by a specialist insurance company who will negotiate the value with the third party on behalf of the contractor.

Telecoms were the lowest at a combined average value of £400. This was initially thought to be surprisingly low, but upon closer investigation it was found that none of the strikes were on fibre optic cables, which are significantly more expensive to repair. Data were obtained from utility A, which specifically detail fibre optic cable damages only. This shows that the average cost of repairing fibre optic cables for the year 2013 was £2850 (based on 606 incidents). At the extreme end, costs ranged up to £130 000 for complex fibre optics. The total paid value of over £600 000 shows how significant the repair cost alone of utility strikes can be for the operational revenue of a business.

The indirect costs are much harder to quantify as many of these are often 'hidden' in overheads, being absorbed as part of doing the 'day job' or exceptional expenditure, and are thus difficult to trace. Ultimately they lead to a negative impact on the financial performance of the business (the 'bottom line'). Thus, an improved understanding and quantifications of these costs will present a powerful motivating factor for contractors to be more proactive in reducing the frequency of incidents. The problem became visible when client B (aviation), for example, had a utility strike on its site that left the airport out of action for a number of hours. The repair cost was recorded as approximately £4000. Clearly, the actual (indirect) cost of having a major airport at a standstill would be far beyond this. It could be argued that these costs should come under social and economic costs, as they affect the general public. Nonetheless, client or utility companies would see a financial impact from a loss of their 'general public' customers, who may choose to use other service providers. The companies, consequently, also have an incentive to reduce utility strikes. Their influence to drive improvement cannot be underestimated, as they ultimately pay and employ contractors to work for them.

Table 4 summarises the indirect costs that may be incurred as a result of a utility strike and also whether the cost is relevant to a client, contractor or both. The costs are listed in descending order based on the assumed ease of measurement (easiest to measure at the top).

7. Conclusions

This paper has analysed utility strikes from nine organisations comprising 3348 incidents, with the aim to discern any patterns in the data. It was interesting to note that the different organisations collect their data according to different levels of detail. Based on this, and the limitations this puts on any industry-wide analysis, this research recommends using the USAG method of recording data, as well as industry-wide sharing of the data.

The key conclusions from analysing the data are listed below.

- Most utility strikes damaged low-voltage electricity and telecom cables, with the latter disproportionately likely to be damaged by operatives using breakers or roadsaws.
- A peak incident occurrence time was observed between 09:00 to 12:00. Companies should monitor their statistics for such patterns and use measures such as targeted text reminders, which have been shown to be successful in reducing incidents.
- Hand tools accounted for the highest proportion of utility strikes by tool, often despite pre-excavation scans detecting the location of a buried utility. This needs to be addressed by further analysis of behavioural factors that may be the underlying cause.

Ref.	Cost	Incurred by	Method of measurement
1	Back office support	Contractors, clients	Record the amount of time spent by staff in dealing with the incident. Multiply by value of time (i.e. pay) to gain total cost
2	Additional materials	Contractors	Record the spending on extra materials and equipment as a result of the incident
3	Lost production as work stops for repairs	Contractors	Record the amount of standing time before work is resumed. Multiply by value of personnel time to gain total cost
4	Programme implications	Contractors	Record extra time added to the project programme and multiply by value of resources required. If working under permits with a deadline, expenditure on seeking an extension or remobilising the site in the future should be recorded
5	Contractual penalty clauses invoked	Contractors	Record charges or reduction in payment if client imposes any penalties based on contractual agreement
6	Fines from the Environment Agency or HSE	Contractors	Log the value of fine imposed for environmental damage or failure to follow health and safety law/procedures
7	Compensation to injured operatives, payment of replacement labour	Contractors	Monitor the value of the time that an injured employee is on paid leave as a result of the incident. Record any compensation payments made as well as expenditure on training and paying replacement operative(s)
8	Legal costs	Contractors	Record the fees paid if the cost of claims or compensation is disputed and requires legal attention
9	Loss of business	Clients	Measure the amount of time that an asset (e.g. airport runway, railway, and so on) is out of action. Calculate the loss of income for this duration based on revenue earned at a comparable time. In the case of utility clients, record if any customers leave as a result of the incident
10	Increased insurance premiums	Contractors	Depends on how a contractor procures insurance. For policies relating specifically to utility strike cover, the increase in premiums could be calculated. However, this will be difficult to attribute to specific incidents. Increases in more general liability policies may be difficult to relate unless the insurer specifies the portion of the increase caused by service strikes.
11	Reduced chances of winning future work	Contractors	Unlikely to be a tangible measurement unless a future client specifically disqualifies the contractor based on utility strike incidents
12	Reputational damage	Contractors, clients	As above (11). Will be difficult to attach a monetary value to reputation
13	Loss of shareholder value	Contractors, clients	The links between specific incident expenses and shareholder value would be tenuous given the complexity of the market. Sharp drops in market value caused by major incidents could be recorded

Table 4. Indirect costs and methods of measurement listed in descending order based on assumed ease of measurement

- Large excavators and mini diggers were the second most likely tool to cause utility strikes.

For utility strikes to be assessed completely with respect to their true costs, not only to the contractor, but also the client, service provider, the public and the environment, the true costs of these incidents were assessed. The direct costs were easy to quantify from insurance data and the average repair costs were electric: £970; gas: £485; telecoms: £400; fibre optic: £2800; water: £300–980. The indirect costs were harder to quantify as part of this research, but were summarised together with a proposed methodology for assessment. This is subject to further research.

8. Practical relevance

Many organisations strive to reduce utility strike incidents by employing state-of-the-art equipment and training. However, incidents still occur. Reasons of industry confidentiality mean that it has not been possible to obtain an industry-wide picture of any patterns and commonality. This research for the first time managed to access data from a wide range of organisations. It gives these and others a better understanding of when utility strikes occur, what causes them and their costs. This can be used to reduce utility strike rates in the future and will be supported by the approaches promoted in the recently published BSI PAS128 (BSI, 2014) specification. It also highlighted the need to have a common data structure in the future.

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REFERENCES

Barhale (2006) *Tool Box Talk – Underground Services*. See http://intranet.scottishwatersolutions.co.uk/portal/page/portal/SWS_PUB_HEALTH_AND_SAFETY/SWSE_PG_HEALTH_AND_SAFETY/BP%20Information/Site%20Mobilization/Barhale%20-%20TBT%20Avoiding%20Underground%20Services.pdf (accessed 03/12/2013).

Bernold L (2003) Economic model to optimize underground utility protection. *Journal of Construction Engineering and Management* **129(6)**: 645–652.

BSI (2014) *PAS 128:2014: Specification for Underground Utility Detection, Verification and Location*. BSI, London, UK.

CGA (Common Ground Alliance) (2012) *CGA DIRT Analysis and Recommendations 2012*. Common Ground Alliance, Alexandria, USA.

CGA (2013) *CGA Best Practices 10.0*. Common Ground Alliance, Alexandria, USA.

Crummie M (2006) *Analysis of Behavioural Factors Influencing Service Strikes*. Human Engineering Limited, London, UK, Unpublished Report.

Cummins B (2012) *Report into Service Strikes and Utility Damages during Construction Activities*. CECA, Scotland, UK.

Hayes R (2012) *Development of a Sustainability Assessment Methodology for UK Streetworks Projects*. PhD thesis, University of Birmingham, Birmingham, UK.

HSE (Health and Safety Executive) (2014) *HSG47: Avoiding Danger from Underground Services*. Her Majesty's Stationery Office, London, UK.

McMahon W, Evans M, Burtwell M and Parker J (2006) *Minimising Street Works Disruption: The Real Costs of Street Works to the Utility Industry and Society*. UKWIR, London, UK, UKWIR Report 05/WM/12/8.

Sanghvi A (1982) Economic costs of electricity supply interruptions: US and foreign experience. *Energy Economics* **4(3)**: 180–198.

USAG (Utility Strike Avoidance Group) (2013) *Toolkit – Utility Strike Avoidance Group*. See http://www.utilitystrikeavoidancegroup.org/toolkit.html (accessed 04/03/2014).