Analysis of the Major Causes of Poor Quality As-built Records of Underground Utilities

Xueqing Zhang* and Di Wu

Department of Civil and Environmental Engineering, The Hong Kong University of Science and Technology
Hong Kong, China

Abstract: In many cities, the underground beneath public roads is intricate with heterogeneous utilities. The situation gets worse where industrial sites are adjacent to residential areas and consequently utilities for industrial purposes and those for the daily life of people are intertwined. In striking contrast, as-built records of underground utilities are often inaccurate and unreliable so that the word “as-built” somehow loses its meaning. The lack of the actual spatial positioning information of various utilities makes it very difficult for road authorities to manage the installation and operation of various utilities beneath public roads and to manage their own road works and services as well. Poor as-built records also affect the performance and profitability of utility companies whose financial success depends on their ability to place facilities and provide services to customers in a timely and cost-effective way, which to some extent depends on the availability of accurate as-built records. This study investigates the main causes of poor as-build records of underground utilities with an aim to shed some insight on what appropriate policies can be established on the side of the government and what workable codes of practice can be implanted on the side of utilities companies such that the quality of as-built records can be efficiently improved by the joint efforts of government and industry. Accurate as-built information will play an irreplaceable role in urban planning, project design and construction, utilities operation and management, and ensuring order and efficiency in underground space utilization.

Keywords: Underground space, utilities, as-built record, road excavation, utilities management

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1 INTRODUCTION

Nowadays, it is not surprising when utility companies or their contractors open a public road in the urban area of a metropolis anywhere around the world and find that the underground is intricate with heterogeneous utilities and there is no space to install new ones. For example, in Mainland China, there are on average around 34 km of underground utility lines per square kilometer of public road (China Association of City Planning 2012). In Hong Kong, there are approximately 47 km of underground utility lines under each kilometer of road. Such density numbers are still increasing, with more and more utility companies involved in various utilities services such as electricity, telecommunication, gas, water, and sewerage. The situation gets worse where industrial sites are adjacent to residential areas and consequently utilities for industrial purposes (e.g., chemicals and flammable and toxic liquids) and those for the daily life of people (e.g., telecommunication, electricity, drinking water and sewerage) are intertwined, posing a potential threat to the community and the lives and properties of the people.

In striking contrast to the large quantities of utility facilities, as-built records of utilities are often inaccurate and unreliable.

*Corresponding author. Email: zhangxq@ust.hk

For example, Quiroga et al. (2002) developed a geographic information system model to represent the positions of utility facilities located within the right-of-way and their associated attribute data such as ownership, purpose, size, type, and other pertinent characteristics. In an attempt to evaluate the spatially positional accuracy and completeness of the existing data, Quiroga found that many drawings were not scaled or the distance information of the existing utilities included in the installation notice approval was not consistent with what was finally installed in the field. In only 21% of the cases, the as-built drawings contained a reference with respect to the right-of-way line, and 20% of the maps had a geometric scale. The spatial data quality was at best weak (Wilde et al. 2002). Marvin and Slater (1997) estimated that only half of the utility as-built records in the USA were accurate. The word “as-built” lost its meaning since it seldom reflected the actual condition of buried facilities (Anspach 2010).

The large quantities of different types of utilities beneath public roads and the lack of a clear picture of the actual spatial positions of such utilities makes it very difficult for road authorities not only to make a decision on whether to allow new utilities to be installed but also to deliver and manage their own road works and services in a timely and cost-effective way.
As asserted by Marvin and Slater (1997), road authorities in most cities have limited jurisdiction in vetting underground utility alignments and do not possess sufficient and reliable information of the underground utilities to support the decision whether to approve the proposals of excavations in public roads. Road authorities often feel themselves possessing “insufficient and inadequate knowledge about what is where” (Beck et al. 2007) and regard managing underground utilities as “a spaghetti subsurface problem” (Oude 1992). Furthermore, from a commercial perspective, poor as-built records also affect the performance and profitability of utility companies. The financial success of these companies depends on their ability to place facilities and provide service to customers as quickly as possible (Wilde et al. 2002), which to some extent depends on the availability of accurate as-built records.

High quality as-built records can provide useful support and reliable references to road authorities and utilities companies as well. Accurate information will play an irreplaceable role in urban planning, project design and construction, and utilities operation and management, securing community safety and minimizing disruption in civil engineering projects, ensuring order and efficiency in underground space utilization. This study investigates the main causes of poor as-build records of underground utilities with an aim to shed some insight on what appropriate policies can be established on the side of the government and what workable code of practice can be implanted on the side of the utilities companies such that the quality of as-built records can be efficiently improved by the joint efforts of government and industry.

2 PROBLEMS ASSOCIATED WITH POOR QUALITY AS-BUILT RECORDS

Incomplete and inaccurate as-built records have become one of the key reasons of ineffective utilization of underground space, unnecessary and frequent road excavations, additional time and costs, poor logistics management and work organizations, damage to buried utilities, and accidents of injuries and deaths (Beck et al. 2009; Gill 2006; Jeong et al. 2004; Quiroga et al. 2011; Tang 2001).

2.1 Accidents Associated with Poor As-built Information

In the USA, there are 20 million miles of buried utilities, which were unintentionally damaged approximately once per minute, resulting in service disruptions, repair costs, and even serious injuries and deaths (Common Ground Alliance 2015). For example, on June 7, 2010, a truck-mounted power auger from C&H Power Line Construction struck and punctured a 36-inch-diameter natural gas transmission pipeline and ignited gas, causing 1 death, 6 severe injuries and a damage cost of US$1,029,000. The direct cause of this accident was the lack of permanent markers to locate the underground facilities before the excavation started (National Transportation Safety Board 2016). Common Ground Alliance (2017) reported that a conservative estimation as much as US$1.5 billion of the societal costs was associated with the excavation damages to buried utilities in 2016.

In China, it was reported that there were 156 utility accidents in Beijing in 2004 and 35.3% of them were caused by gas pipes broken by excavations (China Association of City Planning 2012). There were 27 severe accidents related to underground utilities between 2009 and 2013 in Mainland China, causing a total casualty of 117 people. 53% of the accidents were caused by excavations due to inaccurate information of underground utilities (China Association of City Planning 2012). It was reported that 10kV cables were damaged 117 times by excavations from January to September 2016 in Mainland China (China Association of City Planning 2012). On July 28, 2010, a severe explosion took place in Nanjing Number Four Plastic Factory (Nanjing is the capital of Jiangsu Province), due to the contact of flame and propylene leaked from an underground pipe damaged by excavation machinery. The blast flattened most of the buildings in a 100m radius, killing 13 and injuring 120 people (Shi and Will 2010). According to the statistics data from the Electrical and Mechanical Services Department of Hong Kong (Leung 2007), from 1999 to 2005, around 400 electricity cable damage incidents occurred each year involving third party damage. In November 2012, two workers hired by the Hong Kong Hospital Authority to maintain its electricity system in Mong Kok were seriously burned after digging into a power cable (Nextmedia 1967).

2.2 Time Delay and Cost Overrun

In terms of installation and maintenance of underground utilities, if as-built information cannot depict a reliable picture of the underground, contractors may have to excavate several times to identify suitable space to lay and position utilities or to find the utilities that need maintenance and decide what methods to be used to avoid damage to other utilities. For example, in 2000, the North and South Kowloon Sewerage treatment project that involved 5.8km long sewers in Hong Kong was prolonged due to uncharted underground utilities as most of the buried utilities were found to deviate substantially from the as-built records. Prolongation and re-measurement of underground utilities resulted in an additional cost of HK$148 million (Environment and Food Bureau 2000). Multiple excavations also increase disruption to the general public who use the roads, which have to be closed or partially closed in the process of carrying out the installation or maintenance work.

In addition to time delay and cost overrun to utility works themselves, unavailable or inaccurate as-built records of underground utilities often lead to time delay and cost overrun to other types of construction projects. One case to the point is the West Kowloon terminus project in Hong Kong, which was significantly postponed due to the complex and intricate network of various kinds of utilities under Jordan Road and unreliable as-built records, causing an extra cost of HK$4.62 billion (MTR Corporation Limited 2014).

3 CAUSES OF POOR QUALITY AS-BUILT RECORDS

3.1 Approaches to Identifying Causes

Three approaches have been taken to identify the major causes of poor quality as-build records of underground utilities: (1) literature review, (2) interview with local experts and practitioners in various utility services, and (3) questionnaire survey.

Concerning approach 2, the writers have worked on a consultancy project for the Highways Department of Hong Kong, and one objective of this project is to develop a software prototype of an underground space occupation management system for utilities underneath public roads. One key function of this system is “clash analysis” that detects possible conflicts between a proposed utility alignment and the existing utility facilities and explores feasible routes for the proposed alignment. In the trial process of this prototype, users of some utility companies questioned the reliability of the clash analysis results as they were not confident in the quality of the as-built records used in the system, which were provided by the utility companies involved. Interviews were conducted with a number of staff from companies that used this prototype in the trial process to identify the causes of poor quality as-built records.

Concerning approach 3, in order to develop practical strategies for improved utilization of the underground space beneath public roads, a questionnaire survey was conducted in 2014 to investigate the views of experts and practitioners in various utility services. Through the survey the writers intend to delve into the views of experts and practitioners on some key issues that have to be considered in such strategies. One of the key issues is the causes of poor quality as-built records.

In the questionnaire, respondents are requested to rate the six causes discussed in Section 3.2 on a scale of 1 to 5 (1 = not significant, 2 = fairly significant, 3 = significant, 4 = very significant, 5 = extremely significant). Respondents are also given an option to indicate and rate additional causes.

### 3.2 Major Causes Identified

The three approaches have enabled the identification of six major causes of poor quality as-build records, which are discussed in the following.

**Cause 1 – Overlooked or lost as-built records:** The actual positions and conditions of the utilities were not accurately or adequately documented in the as-built records. For example, some as-built records even did not contain depth-of-cover of the buried utilities and some had topological errors. In addition, original data produced in hardcopy might be scrapped; even if not scrapped, it is difficult to find hardcopy as-built records of utilities constructed long time ago.

**Cause 2 – Physical features of references changed or inconsistent references:** Errors in the as-built records may occur when the physical features of references change or inconsistent references are used. For example, as-built records often use “depth of cover” as the sole reference to the vertical position of the buried utilities whereas the recognized geographical elevation datum is rarely used. Errors in the as-built records will occur when the amount of cover changes due to construction work or erosion.

**Cause 3 – Limitation of current technologies and methods:** Some utility companies asserted that the current level of data quality was the best they could get with the current technology and equipment used in their companies. As-built records may not be accurate or complete due to compatibility and interoperability problems of diverse data format and software used, or to device malfunction and improper operations.

**Cause 4 – As-built records not updated by owner:** As-built records are reliable at the time the utility is installed if the as-built information is well documented right after the installation. However, as-built records may be significantly deviant from the buried utility if the records were generated some time ago and had not been updated when changes were made to the buried utility, for example, a utility company may relocate, remove or abandon its utilities.

**Cause 5 – Mistakes in interpreting, converting and digitizing original as-built records:** The different requirements, alternative knowledge and perspectives, and the heterogeneous data contents and formats of different organizations may lead to human mistakes in the interpretation, conversion and digitization of original as-built records.

**Cause 6 – Utility positions changed by a third party without notification:** For example, a utility company or its contractor may encounter the problem of insufficient underground space for laying a utility. In order to create space and finish the installation work without delay, the company/contractor might cut corners by relocating utilities already buried there before without notifying the owners of those existing facilities.

### 4 QUESTIONNAIRE SURVEY

#### 4.1 Key Stakeholders in Underground Utilities Management

Stakeholders in underground utilities management are broadly classified into three categories: owners, consultants, contractors and government authorities. Owners refer to public and private companies that provide utility facilities and associated services. Consultants are normally the designer and or draftsman of utility works and may be affiliated to a particular owner. They select the routes for different design possibilities and assess their impact on the neighbourhood based on available information of underground utilities. Contractors are responsible for the installation and maintenance of utilities. They play an important role in the updating process of utility information as possess actual as-built data first in the installation and late in the maintenance and replacement of utilities. They are in a better position than other stakeholders in finding discrepancies between the buried utilities and the stored as-built records and timely updating as-built information in the process of construction, maintenance or replacement of utilities. Government authorities regulate the utilization of underground space and the excavation of public roads. They usually have general guidelines and specific requirements on
utility companies regarding the installation and maintenance of utilities beneath public roads and road excavations for such purposes; some requirements may be related to the keeping and updating of as-built records.

4.2 Demographic of Respondents

101 hardcopies of the questionnaire were distributed and 68 received (response rate 67.33%), of which 2 were not complete. Hence, 66 questionnaires were considered valid. The distribution of respondents is shown in Table 1. More than half of the respondents (54.5%) have at least 15 years of working experience. 53 respondents (80.3%) are from utility companies with 9 from public owners (13.7%) and 44 from private owners (66.6%); 6 respondents (9.1%) are from contractors; 7 respondents (11.8%) are from consulting firms. Public owners include Highways Department (providing services related to street lights), Water Supply Department (providing services related to drinkable water) and Drainage Services Department (providing services of sewerage and storm-water management). Private owners involve 11 companies in utility services of sewerage, water, electricity and gas.

<table>
<thead>
<tr>
<th>Type of utility</th>
<th>Number</th>
<th>Percentage</th>
</tr>
</thead>
<tbody>
<tr>
<td>Telecommunication</td>
<td>34</td>
<td>51.5%</td>
</tr>
<tr>
<td>Sewerage</td>
<td>13</td>
<td>19.7%</td>
</tr>
<tr>
<td>Water</td>
<td>8</td>
<td>12.1%</td>
</tr>
<tr>
<td>Electricity</td>
<td>6</td>
<td>9.1%</td>
</tr>
<tr>
<td>Gas</td>
<td>4</td>
<td>6.1%</td>
</tr>
<tr>
<td>Street lights</td>
<td>1</td>
<td>1.5%</td>
</tr>
<tr>
<td>Total</td>
<td>66</td>
<td>100%</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Type of stakeholder</th>
<th>Number</th>
<th>Percentage</th>
</tr>
</thead>
<tbody>
<tr>
<td>Public utility owner</td>
<td>9</td>
<td>13.7%</td>
</tr>
<tr>
<td>Private utility owner</td>
<td>44</td>
<td>66.6%</td>
</tr>
<tr>
<td>Contractor</td>
<td>6</td>
<td>9.1%</td>
</tr>
<tr>
<td>Consultant</td>
<td>7</td>
<td>10.6%</td>
</tr>
<tr>
<td>Total</td>
<td>66</td>
<td>100%</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Respondent</th>
<th>Number</th>
<th>Percentage</th>
</tr>
</thead>
<tbody>
<tr>
<td>&lt; 5 years</td>
<td>19</td>
<td>28.8%</td>
</tr>
<tr>
<td>5 - 9 years</td>
<td>5</td>
<td>7.6%</td>
</tr>
<tr>
<td>10 - 14 years</td>
<td>6</td>
<td>9.1%</td>
</tr>
<tr>
<td>≥ 15 years</td>
<td>36</td>
<td>54.5%</td>
</tr>
<tr>
<td>Total</td>
<td>66</td>
<td>100%</td>
</tr>
</tbody>
</table>

5 RELIABILITY AND VALIDITY TESTING

5.1 Structural Equation Modelling

The structural equation modelling (SEM) technique has been broadly used in research (for example, Golob (2003) and Zhang and Soomro (2016)) to quantify the causal relationships of latent variables that are difficult to be measured directly but rather be assessed indirectly via observable variables (Ullman and Bentler 2003) and to facilitate the assessment of measurement errors in observed variables (Chin 1998). SEM has been explored in this study to evaluate the causal relationships of seven key latent variables (i.e., the satisfaction level of stakeholders on the quality of as-built records, the expectation of stakeholders on as-built records, causes of poor quality as-built records, benefits of good quality as-built records, solutions to improving the quality of as-built records, barriers to the establishment of good quality as-built records, and the willingness of utilities companies to improve the quality of as-built records) and the corresponding observed variables that measure individual latent variables. The whole SEM presentation will not be discussed in this paper due to space limit. Only the part related to the latent variable “causes of poor quality as-built records” and the six observed variables that measure it is discussed here.

Different estimation methods may be used in SEM, for example, covariance-based SEM (CB-SEM) using maximum likelihood estimation and partial least square SEM (PLS-SEM) using regression-based estimation. In this study, PLS-SEM is selected because, unlike CB-SEM, it does not require a large sample size and can be applied to non-normal data. Specifically, individual item reliability and convergent validity are used to evaluate the relationship of the six observed variables and the latent variable.

5.2 Individual Item Reliability

Individual item reliability is the extent to which the measured variables reflect the true score with their respective constructs, assessed by examining the outer loadings. The square of the loadings value indicates the proportion of the variance in the observed variables that is due to the latent variables (Hulland 1999). In order to guarantee the reliability of the estimated model, variables with low loadings should be reviewed as they will add very little explanatory power to the model while attenuating the estimates of the parameters linking the constructs (Nunnally et al. 1967). Regarding the cut-off point of outer loadings, Hulland (1999) thought that variables with loadings of less than 0.4 or 0.5 should be excluded. In practice, a value of around 0.7 is often treated as a threshold value of the outer loadings at the satisfactory level of item reliability (Fornell and Larcker 1981; Chin 1998; Soomro and Zhang 2016). A loading of 0.7 implies more than 50% shared variance between the latent variable and its measurement variables than between the error variance (Carmines and Zeller 1979). As shown in Table 2, all outer loadings are greater than 0.7, demonstrating satisfactory item reliability. Additionally, critical t-values for the two-tailed test of all the loadings are 6.482 or larger, indicating a high level of statistical significance (significance level = 0.01) (Hair et al. 2011).

5.3 Convergent Validity

Convergent validity measures the internal consistency of the latent variables in relation to their measurement variables (Hulland 1999). In PLS-SEM, three tests are commonly used to determine the convergent validity: Cronbach’s alpha, composite reliability, and average variance extracted. Cronbach’s alpha is the coefficient of reliability that is measured by underlining measurement items of a single one-dimensional latent construct. Composite reliability uses the item loadings obtained within the theoretical model to measure the internal consistency, and its interpretation is often regarded as the same as Cronbach’s alpha. Average variance extracted measures the amount of variance that is captured by the construct in relation to the amount of variance due to measurement error (Fornell and Larcker 1981).
Table 2. Results of outer loadings, Cronbach’s alpha, composite reliability and average variance extracted

<table>
<thead>
<tr>
<th>Item Code</th>
<th>Measurement variable</th>
<th>Outer loading</th>
<th>t-value</th>
<th>Composite reliability</th>
<th>Cronbach’s alpha</th>
<th>Average variance extracted</th>
</tr>
</thead>
<tbody>
<tr>
<td>CP1</td>
<td>Utility positions changed by a third party without notification</td>
<td>0.753</td>
<td>7.848</td>
<td></td>
<td>0.912</td>
<td>0.885</td>
</tr>
<tr>
<td>CP2</td>
<td>Physical features of references changed or inconsistent references</td>
<td>0.822</td>
<td>6.482</td>
<td></td>
<td>0.912</td>
<td>0.634</td>
</tr>
<tr>
<td>CP3</td>
<td>As-built records not updated by owner</td>
<td>0.729</td>
<td>8.477</td>
<td></td>
<td>0.912</td>
<td>0.512</td>
</tr>
<tr>
<td>CP4</td>
<td>Overlooked or lost as-built records</td>
<td>0.838</td>
<td>8.919</td>
<td></td>
<td>0.912</td>
<td>0.643</td>
</tr>
<tr>
<td>CP5</td>
<td>Mistakes in interpreting, converting and digitizing original as-built records</td>
<td>0.823</td>
<td>11.430</td>
<td></td>
<td>0.912</td>
<td>0.634</td>
</tr>
<tr>
<td>CP6</td>
<td>Limitation of current technologies and methods</td>
<td>0.808</td>
<td>8.986</td>
<td></td>
<td>0.912</td>
<td>0.643</td>
</tr>
</tbody>
</table>

For Cronbach’s alpha and composite reliability, a threshold value of 0.7 is considered as an acceptable level of internal consistency (Nunnally et al. 1967; Zhang 2006). As for average variance extracted, Fornell and Larcker (1981) suggested a score of 0.5 as being acceptable. With reference to these recommended evaluation criteria of convergent reliability, the results as shown in Table 2 indicate good internal consistency, that is, the six observed variables do measure the latent variable.

6 SIGNIFICANCE ANALYSIS OF THE SIX CAUSES

6.1 Weighted Average Score

WAS, the weighted average score in the rating of each of the 6 causes of poor as-built records, is calculated using the following formula:

$$WAS = \frac{\sum(n \times s)}{N}$$

where $s$ = a particular rating given to a cause on a scale of 1 to 5 (1 = not significant, 2 = fairly significant, 3 = significant, 4 = very significant, 5 = extremely significant); $n$ = the number of responses to a particular rating; and $N$ = the total number of responses to a cause.

Table 3 shows the weighted average score and standard deviation in the rating of the significance of the 6 causes based on all responses. The weighted average scores of all 6 causes ranging from 3.44 to 3.74 indicate that the six causes are significant or very significant causes to poor quality as-built records.

6.2 Agreement across Stakeholders and Utility Sectors

It is useful to examine the similarity and difference in the rating of the 6 causes (1) between different types of stakeholders, including owners (public and private), consultants and contractors, and (2) between respondents of different types of utility services, including electricity, water, telecommunication, sewerage, gas and street lights. This kind of “agreement analysis” enhances the understanding of the perspectives of different groups of people on the relative importance of a number of items (Zhang 2005a; Zhang 2005b), which in this paper are the six causes of poor quality as-built records. Parametric and non-parametric methods are explored to further test whether the significance ratings of different types of stakeholders are statistically different.

6.3 Parametric Tests

In general, parametric methods are regarded more powerful than non-parametric methods (Hsu 1996). In parametric methods such as two-sample $t$-test or one-way ANOVA, a null hypothesis is tested to determine whether the ratings between two types of stakeholders are significantly different according to a threshold probability. However, one assumption in parametric methods is that the experimental data should follow a normal distribution. Parametric methods would not be appropriate if such an assumption does not hold. In this study, one-sample Kolmogorov-Smirnov test is conducted to determine if the ratings of the stakeholders follow a normal distribution. Monte Carlo simulation is also adopted with confidence level set to 99%, and the simulation result is based on 10,000 sampled tables with starting seed 2,000,000. As shown in Table 4, the test result indicates that the ratings deviate significantly

Table 3. Summary of overall responses

<table>
<thead>
<tr>
<th>Item Code</th>
<th>Cause of Poor As-built Records</th>
<th>Weighted Average Score</th>
<th>Standard Deviation</th>
</tr>
</thead>
<tbody>
<tr>
<td>CP6</td>
<td>Utility positions changed by a third party without notification</td>
<td>3.74</td>
<td>0.771</td>
</tr>
<tr>
<td>CP2</td>
<td>Physical features of references changed or inconsistent references</td>
<td>3.67</td>
<td>0.730</td>
</tr>
<tr>
<td>CP4</td>
<td>As-built records not updated by owner</td>
<td>3.67</td>
<td>0.771</td>
</tr>
<tr>
<td>CP1</td>
<td>Overlooked or lost as-built records</td>
<td>3.65</td>
<td>0.754</td>
</tr>
<tr>
<td>CP5</td>
<td>Mistakes in interpreting, converting and digitizing original as-built records</td>
<td>3.59</td>
<td>0.784</td>
</tr>
<tr>
<td>CP3</td>
<td>Limitation of current technologies and methods</td>
<td>3.44</td>
<td>0.747</td>
</tr>
</tbody>
</table>
from a normal distribution \((p < 0.05)\). Therefore, parametric methods are not appropriate for agreement analysis across different types of stakeholders.

### 6.4 Non-Parametric Tests

In view of the inapplicability of parametric methods, the writers turn to two non-parametric methods, Mann-Whitney U test and Kruskal-Wallis H test. The Mann-Whitney U test is a nonparametric alternative to the independent \(t\)-test in comparing differences between two independent groups when the dependent variable is either ordinal or continuous, but not normally distributed while the Kruskal-Wallis H test is a non-parametric alternative to the one-way ANOVA, allowing the comparison of more than two independent groups (Corder and Foreman 2009).

### 6.5 Comparison of Different Types of Stakeholders

Table 5 summarizes the responses of different types of stakeholders. Here owner refers to a public or private utility company and non-owner refers to a consultant, contractor, or government authority. Tables 6 – 8 show the Mann-Whitney U test results in terms of the WAS values between different types of stakeholders. The results indicate that there is no statistical difference between owner and non-owner responses (Table 6), between private and public owner responses (Table 7), and between consultant and contractor responses (Table 8).

It should be noted that while the asymptotic method indicates statistical difference between contractor and consultant responses on the cause of “as-built records not updated by owner” (CP4), the exact test method and Monte-Carlo test method show no significant difference (please refer to Table 8 for details). Exact test method and Monte-Carlo test method are often regarded as a better option than asymptotic method for small sample sizes (Sen et al. 2010). Considering the relatively small sample size of contractors and consultants, the results from the exact test method and the Monte-Carlo test method are adopted, that is, there is no significant difference between contractors and consultants.

### 6.6 Comparison of Different Types of Utility Services

Table 9 shows the statistics of responses to the six causes from Table 5.
#### Table 7. Mann-Whitney U test result for comparison of private and public owner responses

<table>
<thead>
<tr>
<th>Item Code</th>
<th>Mann-Whitney U</th>
<th>Wilcoxon W</th>
<th>Z</th>
<th>Asymp. Sig. (2-tailed)</th>
<th>Exact Sig. [2*(1-tailed Sig.)]</th>
<th>Monte Carlo Sig. (2-tailed)</th>
</tr>
</thead>
<tbody>
<tr>
<td>CP1</td>
<td>164.500</td>
<td>209.500</td>
<td>−0.858</td>
<td>0.391</td>
<td>0.434</td>
<td>0.412</td>
</tr>
<tr>
<td>CP2</td>
<td>133.000</td>
<td>178.000</td>
<td>−1.692</td>
<td>0.091</td>
<td>0.128</td>
<td>0.106</td>
</tr>
<tr>
<td>CP3</td>
<td>184.500</td>
<td>1,174.500</td>
<td>−0.357</td>
<td>0.721</td>
<td>0.753</td>
<td>0.754</td>
</tr>
<tr>
<td>CP4</td>
<td>143.000</td>
<td>188.000</td>
<td>−1.426</td>
<td>0.154</td>
<td>0.200</td>
<td>0.154</td>
</tr>
<tr>
<td>CP5</td>
<td>195.000</td>
<td>240.000</td>
<td>−0.077</td>
<td>0.938</td>
<td>0.954</td>
<td>0.910</td>
</tr>
<tr>
<td>CP6</td>
<td>150.500</td>
<td>195.500</td>
<td>−1.211</td>
<td>0.226</td>
<td>0.265</td>
<td>0.238</td>
</tr>
</tbody>
</table>

Note: 1. Exact Sig.: Not corrected for ties; 2. Values in bold are statistically different at 5% sig. level; 3. Monte Carlo simulation is based on 10,000 sampled tables with starting seed 1066061003, adopted with confidence level set to 99% in regard to the small sample size.

#### Table 8. Mann-Whitney U test result for comparison of contractor and consultant responses

<table>
<thead>
<tr>
<th>Item Code</th>
<th>Mann-Whitney U</th>
<th>Wilcoxon W</th>
<th>Z</th>
<th>Asymp. Sig. (2-tailed)</th>
<th>Exact Sig. [2*(1-tailed Sig.)]</th>
<th>Monte Carlo Sig. (2-tailed)</th>
</tr>
</thead>
<tbody>
<tr>
<td>CP1</td>
<td>18.500</td>
<td>46.500</td>
<td>−0.388</td>
<td>0.698</td>
<td>0.731</td>
<td>0.728</td>
</tr>
<tr>
<td>CP2</td>
<td>10.000</td>
<td>38.000</td>
<td>−1.927</td>
<td>0.054</td>
<td>0.138</td>
<td>0.145</td>
</tr>
<tr>
<td>CP3</td>
<td>15.000</td>
<td>43.000</td>
<td>−0.921</td>
<td>0.357</td>
<td>0.445</td>
<td>0.501</td>
</tr>
<tr>
<td>CP4</td>
<td>8.000</td>
<td>36.000</td>
<td>−2.137</td>
<td>0.033</td>
<td>0.073</td>
<td>0.074</td>
</tr>
<tr>
<td>CP5</td>
<td>12.000</td>
<td>40.000</td>
<td>−1.371</td>
<td>0.170</td>
<td>0.234</td>
<td>0.266</td>
</tr>
<tr>
<td>CP6</td>
<td>13.000</td>
<td>41.000</td>
<td>−1.315</td>
<td>0.189</td>
<td>0.295</td>
<td>0.290</td>
</tr>
</tbody>
</table>

Note: 1. Exact Sig.: Not corrected for ties; 2. Values in bold are statistically different at 5% sig. level; 3. Monte Carlo simulation is based on 10,000 sampled tables with starting seed 1509375996, adopted with confidence level set to 99% in regard to the small sample size.

#### Table 9. Summary of responses of different types of utilities

<table>
<thead>
<tr>
<th>Item Code</th>
<th>Electricity WAS</th>
<th>SD</th>
<th>Water WAS</th>
<th>SD</th>
<th>Telecommunication WAS</th>
<th>SD</th>
<th>Sewerage WAS</th>
<th>SD</th>
</tr>
</thead>
<tbody>
<tr>
<td>CP1</td>
<td>3.67</td>
<td>0.516</td>
<td>3.5</td>
<td>0.535</td>
<td>3.59</td>
<td>0.783</td>
<td>3.62</td>
<td>0.768</td>
</tr>
<tr>
<td>CP2</td>
<td>3.83</td>
<td>0.753</td>
<td>3.25</td>
<td>0.707</td>
<td>3.56</td>
<td>0.746</td>
<td>4</td>
<td>0.577</td>
</tr>
<tr>
<td>CP3</td>
<td>3.67</td>
<td>0.516</td>
<td>3.38</td>
<td>0.744</td>
<td>3.29</td>
<td>0.676</td>
<td>3.77</td>
<td>0.927</td>
</tr>
<tr>
<td>CP4</td>
<td>3.5</td>
<td>0.837</td>
<td>3.25</td>
<td>1.165</td>
<td>3.71</td>
<td>0.719</td>
<td>3.85</td>
<td>0.689</td>
</tr>
<tr>
<td>CP5</td>
<td>3.5</td>
<td>0.837</td>
<td>3.5</td>
<td>0.756</td>
<td>3.47</td>
<td>0.788</td>
<td>3.85</td>
<td>0.801</td>
</tr>
<tr>
<td>CP6</td>
<td>3.67</td>
<td>0.816</td>
<td>3.25</td>
<td>0.707</td>
<td>3.76</td>
<td>0.819</td>
<td>4.08</td>
<td>0.641</td>
</tr>
</tbody>
</table>

Note: WAS – weighted average score; SD – standard deviation.

The underground beneath public roads is normally intricate with heterogeneous utilities in many cities around the globe. The lack of actual spatial positioning information and poor as-built records of various utilities make it a big challenge for both governmental authorities and utility companies to effectively manage and operate utility as well as road services. Complete and inaccurate as-built records have become one of the key reasons of ineffective utilization of underground space, unnecessary and frequent road excavations, additional time and costs, poor logistics management and work organizations, damage to buried utilities, and accidents of injuries and deaths.

Through literature review, interview with local experts and practitioners in various utility services, and questionnaire survey, 6 major causes of poor quality as-built records have been identified: (1) overlooked or lost as-built records, (2) physical features of references changed or inconsistent references, (3) limitation of current technologies and method, (4) as-built records not updated by owner, (5) mistakes in interpreting, converting and digitizing original as-built records, and (6) utility positions changed by a third party without notification.

Quality as-built records are a prerequisite for efficient and four types of utility services, electricity, water, telecommunication and sewerage. Utility services of gas and street lights are not considered here because the sample sizes of both services are too small, with only 4 responses from gas service and 1 from street lights. The results of the Kruskal-Wallis H are shown in Table 10, which indicate that there is no statistical difference across the four types of utilities services.

### 7 CONCLUSIONS

The underground beneath public roads is normally intricate with heterogeneous utilities in many cities around the globe. The lack of actual spatial positioning information and poor as-built records of various utilities make it a big challenge for both governmental authorities and utility companies to effectively manage and operate utility as well as road services.
cost-effective urban planning, project design and construction, utilities operation and management, and underground space utilization. It is hoped that the output of this study will facilitate the establishment of appropriate policies and workable codes of practice to significantly improve the quality of as-built records by the joint efforts of government and industry.

ACKNOWLEDGEMENT

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**Table 10.** Kruskal-Wallis Test result for responses across different types of utility services

<table>
<thead>
<tr>
<th>Item Code</th>
<th>Chi-Square</th>
<th>df</th>
<th>Asymp. Sig. (2-tailed)</th>
<th>Monte Carlo Sig. (2-tailed)</th>
</tr>
</thead>
<tbody>
<tr>
<td>CP1</td>
<td>0.260</td>
<td>3</td>
<td>0.967</td>
<td>0.967</td>
</tr>
<tr>
<td>CP2</td>
<td>6.186</td>
<td>3</td>
<td>0.103</td>
<td>0.094</td>
</tr>
<tr>
<td>CP3</td>
<td>3.333</td>
<td>3</td>
<td>0.343</td>
<td>0.339</td>
</tr>
<tr>
<td>CP4</td>
<td>2.834</td>
<td>3</td>
<td>0.418</td>
<td>0.437</td>
</tr>
<tr>
<td>CP5</td>
<td>2.198</td>
<td>3</td>
<td>0.532</td>
<td>0.544</td>
</tr>
<tr>
<td>CP6</td>
<td>5.421</td>
<td>3</td>
<td>0.143</td>
<td>0.146</td>
</tr>
</tbody>
</table>

Note: 1. Values in bold are statistically different at 5% sig. level;
2. Monte Carlo simulation is based on 10,000 sampled tables with starting seed 2000000.
New South Wales Street Opening Conference (2009).

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