https://doi.org/10.1016/j.tust.2016.01.026

Exploring Utility System SDI – Managerial and Technical Perspectives

*Lilian S.C. Pun-Cheng *, Wallace W.L. Lai & Ray K.W. Chang*
Department of Land Surveying and Geo-Informatics,
The Hong Kong Polytechnic University, Hunghom, Kowloon, Hong Kong SAR, China

* corresponding author. email: lilian.pun@polyu.edu.hk, tel no.: (852) 2766 5959

Abstract

Spatial Data Infrastructure (SDI) has increasingly been important with the more widespread use of Geo-IT. The term is not new to countries which have adopted geo-information technology for a long time such as Australia, Germany and the United States. In Hong Kong, increasing attention to SDI has been paid from a number of government departments and related professional bodies in recent years. Yet, their work has primarily been concentrated on features on topographic surface. Our underground utility system which consists of diverse types of pipes, power lines and cables in fact also calls for an urgent need of a SDI to ensure both smooth and secure daily operations as well as system management and planning. To achieve setting up a utility SDI for as-built record, identification of essential components with proper definition is the first task, followed by translation into commonly agreed geometric and topologic primitives. From this proposed project, it's also preferable that a prototype platform with representative tested data be developed to enable simple query and network analysis. It is hoped that deliverables from this project can be demonstrated to the industry, making a start to promote Geo-IT technology in enhancing utility data management.

Keywords: Utility spatial data, data infrastructure, 3-D data

1. Introduction

Utility system refers to the laying of pipes, networks or cables for the provisions of everyday life essentials especially for the urban people. This includes water, sewerage, gas, electricity, tele-communication and so on. Information on where, what and functions of these systems are usually owned by individual party and is seldom shared among different parties (Boukhelifa and Duke, 2007). There are two probable reasons – confidentiality in view of competition and the lack of a systematic and thorough inventory. Such practice is not desirable for both operational and security reasons. In Hong Kong, accidents do happen in past years when workers mistakenly broke a gas or water pipe; it takes a long time to trace and fix the problem of a sudden blackout of electricity, water and gas supply. A wide range of underground utilities' condition survey, assessment and diagnostic technologies (Sterling et al. 2009; Hao et al. 2012) is available for input the blackout records to the utility system spatial data infrastructure. Compliance check of the surveyed results can be made according to various data quality levels suggested in USA (ASCE 38-02, 2002), UK (BSI PAS 128, 2014) and Canada (CSA S250, 2011). After carrying out the survey with fairly acceptable accuracy in the compliance check, it is therefore necessary to set up a such a system (Chen and Cohn, 2011) and database (Royal, et al. 2010; Malinowska and Hejmanowski, 2010) to at least identify the main layouts of the different systems. Despite the needs for efficient and effective city administration, the task is challenging in view of the different formats held and the long history of records that are not easy to be retrieved (Beck et al. 2009). Integration or correlation of such information correctly is not an easy and simple task.

The recognition of an integrated data from various sources due to existing data inconsistency is always a popular concern, in which a number of projects have been carried out by various government departments in Hong Kong. This includes integrating the diverse address formats by the Rating and Valuation Department, geographical data modelling services for computerized land information system by the Land Information Centre of Survey and Mapping Office of the Lands Department, implementation of data alignment measures and situational analysis review by the Housing, Planning and Lands Bureau. In particular, integration of condition assessment records of both transport infrastructure/street works at the road surface and the underneath buried utilites is required to build an total management system of city's infrastructures (Rogers et al. 2012). Similar projects have also been carried out in a more complete fashion worldwide. For instance, United States Geological Survey (USGS) has set up a data portal: Geodata http://edc.usgs.gov/geodata/ for public access to its geospatial data. Not only topographic and imagery data, but also social and economic datasets have been integrated for public access. The Swedish demographic database project integrated population datasets (http://www.ddb.umu.se/index_eng.html) for all residents over the past few decades, with which the users can track individual migration at a very detailed level. Yet these are all about mapping socio-economic data on topographic surface. The utility spatial data infrastructure (USDI) is still a very new and challenging idea to be explored. In doing so, the necessary components or features of the different utilities have to be identified and the various feature definitions, spatial format and resolution be standardized. This paper therefore first examines the conventional recording methods and formats of utility data and identifies the problems in contributing to a common spatial database. With the data provided by several utility companies for the same region, a prototype is built to illustrate the concept and suggest further improvements for realizing an integrated and interoperable platform of USDI.

2. Conventional Data Structure for Utilities

In the past, utility records such as position, depth, material, length were often kept in "Book Form" (Mahoney, 1986). During 1970s and early 1980s, AM/FM was emerged to manipulate utility records in the form of digital records, i.e. a utility database (Armstrong, 1992). Being a computer aided cartography (AM) and a system to record business and manage information associated with a map (FM) (Mahoney, 1986), it has the capabilities for automated mapping processes, record keeping, spatial data analysis and data/application integration in two-dimensional space. This technology allows utility companies to perform network analysis, marketing analysis, facilities mapping, keeping records of maintenance and usage.

AM/FM drawings are usually associated CAD, which record and visualize data in graphics or drawings, including depth, diameter, material and type of underground utilities. Different color schemes and/or patterns are adopted to differentiate types of mains/cables/culverts. Levels or layers are set to display different types of underground utilities, however, no spatial data such as depth, specific function can be retrieved. These layers can be switched on and off according to operational needs. Map scale should be controlled to avoid information congestion and confusion. The smaller the scale, the lower the level of details can be visualized. As AM/FM drawings are processed by CAD, they lack spatial relationship among entities (Xing *et al.*, 1998) such as connectivity, adjacency and network zoning. Also, it is a two-dimensional system that emphasizes on creation and management of linear and point features rather than area features (Russomanno, 1998), not to mention the three-dimensional complexity that actually occur in determining the laying of utilities underground. Under a two-dimensional CAD system, depth information of underground utilities are ignored and may lead to misinterpretation. Past practices has been using traditional typical sections, plan views and cross sections, which did not provide sufficient data for integration with 3D modeling (Pilla and Anspach, 2014). Even if a variety of surface geophysical methods like 3D Ground Penetration Radar Tomography has been developed for collecting depth information, it still poses a challenge for smaller utilities and those at great depths underground. As shown in (Figure 1), Sewage Mains and Gas Cable, with different depths, seems to be overlapped and inter-connected by manholes/ valve.

By late 1980s GIS started to embrace into AM/FM systems. Spatial information and attributes of entities were stored in a relational database management system (RDBMS) (Meyers, 1999) separately. With processing both geographical and attribute information, simulations and higher level analysis of facilities are enabled for decision-making, marketing and accounting (Berner *et al.*, 1995). In recent decades, a number of commercial GIS have modelled individual utility system in a separate module taking into account of its own unique rules and cardinal relationships between different feature classes and sub-classes (Armstrong, 2011, Bentley2014). Yet, GIS applications to utility data management is still limited. In the US, only half of the states use GIS application to manage utility conflict data. There is still a clear preference for traditional paper-based approaches to mark up printed drawings or maps (Quiroga and et.al., 2009). For a USDI, not only a detailed and up-to-date database for managing geo-referenced data and other attributes is essential, but also the challenging need of data integrity and data normalization between different databases. This project therefore attempts to integrate the databases of four common utilities, identifies the key information to be shared and the problems during data conversion and integration.

3. Utility Records and Semantics

A utility database, whether of CAD or GIS format, of detailed design or of schematics, usually consists of vast information peculiar to the management and operation needs of a particular network. When forming an integrated database, the identification of key or essential features is of prime importance before an agreed data structure and format can be formulated. Semantics inherent in the drawings or database should be well-understood so that features of common interest can be shared out to form a common database. In this project, record plans of four utility records – Fresh Water, Drainage and Sewage, Gas and Electric Cables supplied from the Water Services Department, Drainage Services Department, Hong Kong Town Gas and China and Light Power Limited respectively for a small (about 100 hectares), old but densely populated region in Tokwawan, Kowloon, Hong Kong are studied in an attempt to establish a prototype USDI.

3.1 Fresh Water

Among the four studied utilities, only records of fresh water are operated and managed by a GIS. Features related to fresh water such as mains, valves, meters, pumping stations are stored in different layers with accurate 2-dimensional geometry (Figure 2a) whereas their attributes such as ID, diameter are stored separately in an attribute table (Figure 2b). A complete network is created whereby all mains are connected to valves with specific cardinal relationships. Hence, not only spatial and connectivity query are made convenient, but also tracing water flows from a source to users and detection of affected areas at times of defective pipe or valve is enabled in such a database.

3.2 Drainage and sewage

In the CAD drawings of sewage, foul and storm water pipes are shown by two different colors: red for foul water drainage and blue for storm water drainage (Figure 3). The same colors apply to their manholes respectively. However, some storm water flowing through the box culverts are shown separately by blue dashed lines. Information concerning drainage ID, drainage diameter, manhole ID, manhole cover level, pipe diameters and depths connecting to the manholes, box culvert ID and its dimensions are all shown as labels in the drawings.

3.3 Gas

For the CAD drawings of Gas, different line colors are used to represent different pressure types (high pressure, mid-pressure, low pressure) of gas pipes, while pressure levels in bar units are stored in the attribute tables in GIS (Figure 4). Descriptions of pipes such as pressure, diameter, depth, state, material, connection type, valve status, syphon type, terminator type and sleeve type are all shown as labels in the drawings.

3.4 Electricity

Different line colors stand for high and low voltage cables and fibre optic whereas the point features are voltage joints, mounted poles, temperature sensing joints, terminations and substations. Labels in the drawing include cable material, cable size, joint type, pole type, temperature sensing joint type, termination type and cable depth (Figure 5).

4. Prototyping a USDI

To set up a utility spatial data infrastructure, there are 3 stages of development:

a) Identify the main purpose and functions of this integrated database

b) Identify the set of features or information that can satisfy the functions

c) Identify a common data model and structure

Why is it necessary to set up a USDI? What functionalities and benefits can be achieved? The answers to these questions are important indicators of how to integrate information. If it is just for viewing purpose, a CAD drawing with the essential features of all utility types tidily arranged together with proper annotations or a legend will be sufficient. However, the intention of a USDI should be more than that. It should enable interactive and selective query of features and their descriptions, provide solutions for planning and emergency response when dealing with different utility types together. For example, to repair a water pipe, it is important to know where to switch off the nearby gas pipes, and vice versa. The geo-database has recently been considered a good solution. In doing so, there must be a set of commonly agreed essential features (of whatever geometry) and/or attributes for general and topological enquiries. Detailed information like ID, size and function for internal operations may not be necessary. Table 1 below suggests the geo-database structure for the features and attributes to be considered from the four studied utilities for establishing a USDI.

From the CAD drawings or GIS database, these linear features have to be topologically constructed, that is the lines have to be interconnected by and terminated as points. Take electricity as an example, all cables need to link a substation at the start, terminate in either a household or lamp post and interconnected at network junction. In this way, a flow direction is generated. In the USDI database, the four utility types are separate layers, each with a linear network. The types of pipe or cable are defined in the line attributes whereas the types of point feature (e.g. hydrant or lateral point) are defined in the node attributes. With accurate position data and geometry, it allows spatial analysis (e.g. adjacency, connectivity, distance enquiry) across different utility types. The followings list some examples of query or analysis functions:

a) automatic derivations of lengths of each cable/pipe and level difference between the start and end point of a pipe/cable;
b) spatial and attribute retrieval of depth/material/diameter of each utility;
c) retrieve and visualize nearby features within a user-specified search range;
d) setting buffer zones and intersect to find out if overlapping of pipe/cable occurs when opening a pit; this may be enabled through 2-D and 3-D environments (Figure 6).

In the experience of constructing a USDI in the studied area, several problems are identified:

a) Entity-Relations model (ER model) needs semantic knowledge of individual utility, so that features and attributes can be organized systematically to allow both geometric and topologic queries and analysis.

b) For geometric information such as depth, diameter and width, units are not the same for all utility types and conversion is necessary.

c) Position data (topographic xy coordinates and depth) of some point features like manholes, valves are more accurate, whereas most line features (especially gas pipes and electricity cables) are just accurate in the sense that these are within a road segment. The depth data, which is preferable for 3-D visualization, is not specific enough in two aspects: i) from which surface datum it refers to and ii) if shown in annotation, it is not clear the depth refers to a point at the two ends, part or the entire line. Without accurate depth data, utilities drawn with accurate width will sometimes found intersect or touch with each other which should not be real (Figure 7). Field survey (Costello, 2007) is therefore needed to retrieve missing information and validate existing information.

d) In the process of conversion from source CAD drawings to a topological geo-database, points and lines are mostly not connected and so involve a lot of edits to generate an interconnected network.

e) The understanding and appreciation of an integrated database are still premature among utility stakeholders, who therefore cannot provide a judgment of what information to be openly shared.

5. Conclusion

This paper has addressed the rising importance of a utility spatial data infrastructure as a result of increasing urbanization. The discussion point is not on a technological innovation, but the conventional managerial difficulties and feasibilities of implementing such a concept due to the accustomed ways of handling historical records. There is no doubt of the benefits from shared, integrated and interoperable data, in particular for extending to 3-dimensional query and visualization. An example is the 3D utility data model proposed in the US strategic highway research program whereby conflict detection and advanced 3D editing functions are developed (Gale and Hammerschmidt, 2015). However, to realize a complete and error-free USDI, the different utility stakeholders still need to come up with a total solution for political, organizational, financial and technical concerns.

Acknowledgements

The work described in this paper was substantially supported by a grant from the Hong Kong Polytechnic University (Project No. G-YJ52). Thanks are also given to the data and advice contributed by the Water Supplies Department and the Drainage Services Department of the Hong Kong SAR Government, as well as the Hong Kong and China Gas Company Limited (Towngas) and the China and Light Power Hong Kong Limited.

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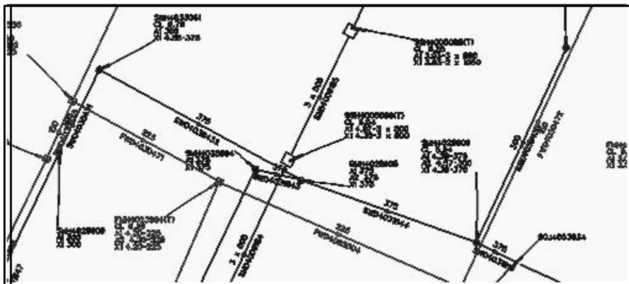
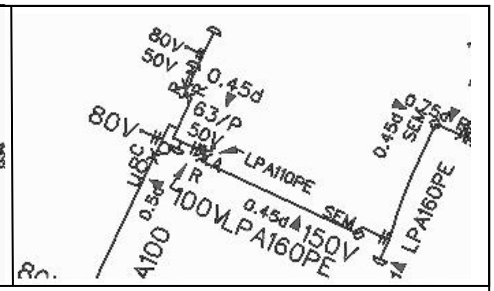




Sewage record drawings

Gas record drawings

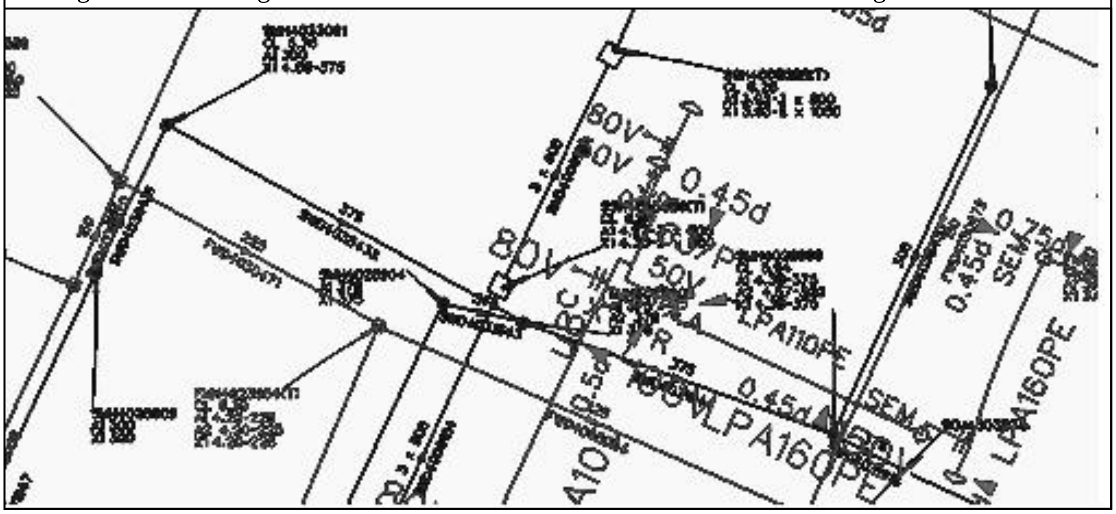
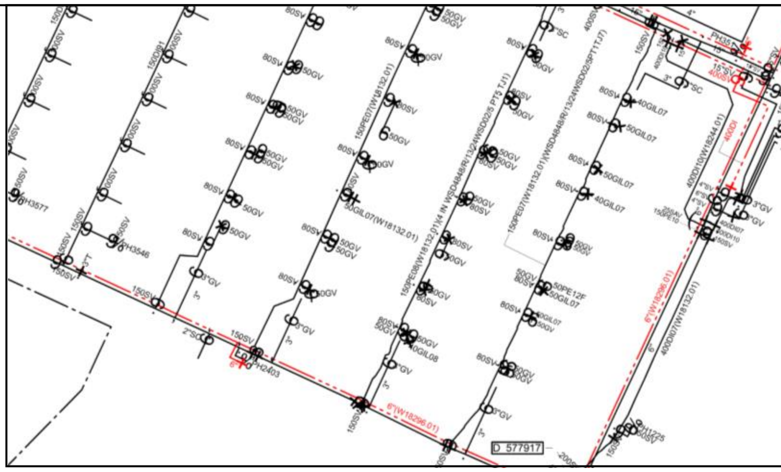


Figure 1 Overlay of both sewage and record drawings



Features	Geometry
Pipes	Line
Valves	Point
Pumps (start)	Point
Hydrant (end in street)	Point
Fitting	Point
Lateral Point (end in household)	Point
Junction	Point
Filter	Point

(a) (b)

OBJECTID *	SHAPE *	FACILITY_ID	MAIN_TYPE	UNITS	DIAMETER	NORM_DIAM	MATERIAL	COMPLETIO	COMMISSIO	STATUS	OWNER	GROUND_SU	SYMBOL_TY	TYPENAME	SHAPE_Len	WM_ID	DIAMETER_
5231	Polyline Z	F04609-11N	11	MM	150	150	PE100	27/8/2012	27/8/2012	SM	WSD	UNG	DSM	DSM	0.854771	F15231	150
5230	Polyline Z	F02186-11NE	11	MM	150	150	DI	1/7/2008	1/7/2008	SM	WSD	UNG	DSM	DSM	0.859667	F15230	150
5229	Polyline Z	F02226-11NE	11	MM	300	300	DI	1/7/2008	1/7/2008	SM	WSD	UNG	DSM	DSM	1.94158	F15229	300
5228	Polyline Z	F02212-11NE	11	MM	80	80	DI	1/7/2008	1/7/2008	SM	WSD	UNG	DSM	DSM	0.82753	F15228	80
5227	Polyline Z	F02221-11NE	11	MM	300	300	DI	1/7/2008	1/7/2008	SM	WSD	UNG	DSM	DSM	2.122333	F15227	300
5226	Polyline Z	F02065-11NE	11	IN	6	152	NIL	<Null>	<Null>	SM	WSD	UNG	DSM	DSM	2.663864	F15226	152
5225	Polyline Z	F02207-11NE	11	MM	100	100	PE100	18/2/2009	18/2/2009	SM	WSD	UNG	DSM	DSM	8.998399	F15225	100
5224	Polyline Z	F02196-11NE	11	MM	300	300	S	18/2/2009	18/2/2009	SM	WSD	UNG	DSM	DSM	0.559664	F15224	300
5223	Polyline Z	F02188-11NE	11	MM	300	300	S	18/2/2009	18/2/2009	SM	WSD	UNG	DSM	DSM	0.557987	F15223	300
5222	Polyline Z	F04330-11NE	11	IN	3	76	NIL	<Null>	<Null>	UC	WSD	UNG	UCM	DSM	93.96266	F15222	76
5221	Polyline Z	F04184-11NE	11	IN	4	102	NIL	<Null>	<Null>	UC	WSD	UNG	UCM	DSM	4.049878	F15221	102
5220	Polyline Z	F04356-11N	11	MM	150	150	DI	21/3/2007	21/3/2007	SM	WSD	UNG	DSM	DSM	0.865273	F15220	150
5219	Polyline Z	F01621-11NE	11	MM	100	100	DI	25/11/2008	25/11/2008	SM	WSD	UNG	DSM	DSM	0.933376	F15219	100
5218	Polyline Z	F01618-11NE	11	MM	200	200	DI	25/11/2008	25/11/2008	SM	WSD	UNG	DSM	DSM	3.085327	F15218	200
5217	Polyline Z	F01605-11NE	11	MM	300	300	DI	25/11/2008	25/11/2008	SM	WSD	UNG	DSM	DSM	162.075798	F15217	300
5216	Polyline Z	F03687-11NE	11	MM	450	450	DI	28/6/2008	28/6/2008	SM	WSD	UNG	DSM	DSM	132.667544	F15216	450

Figure 2 (a) Layers of fresh water features; (b) Attribute table of fresh water database

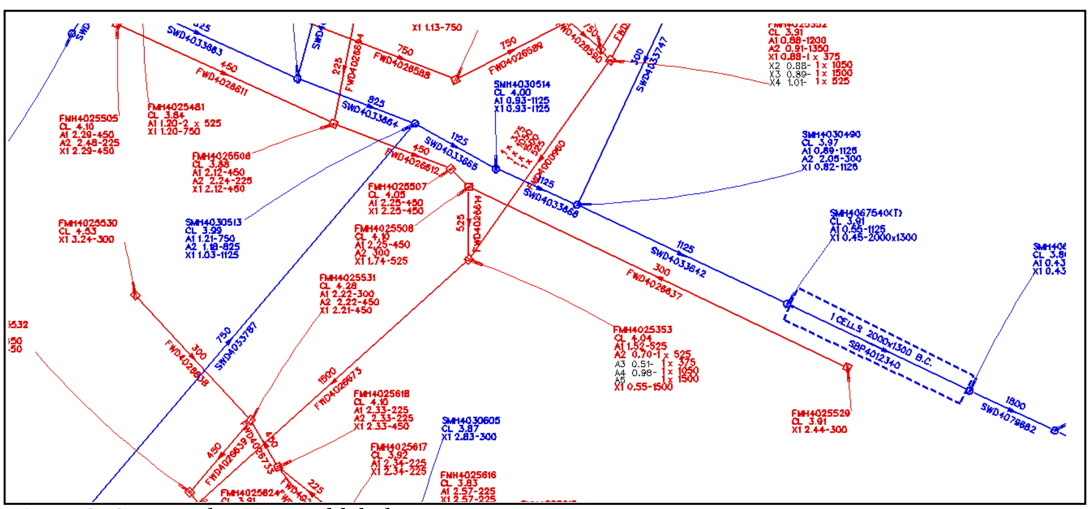


Figure 3 Sewage drawing and labels

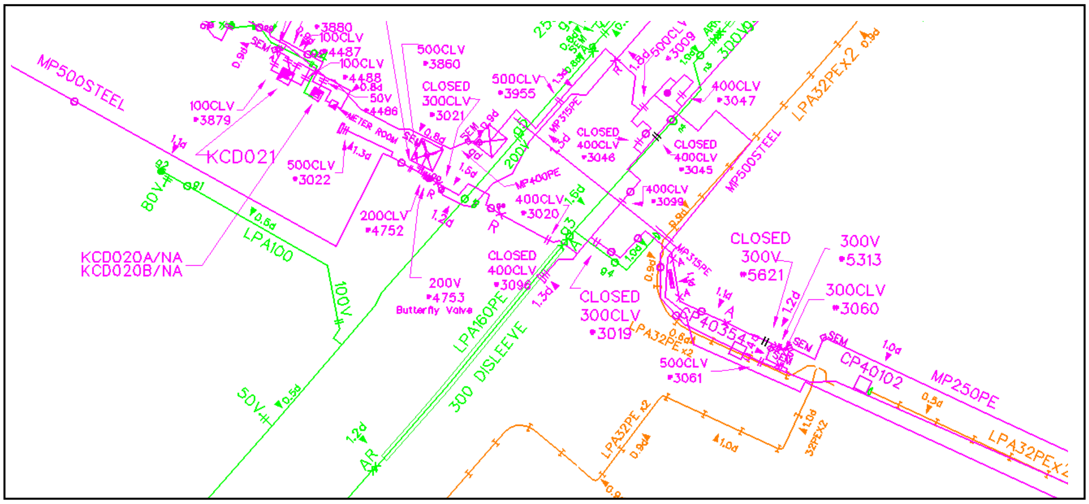


Figure 4 Gas pipe drawings and labels

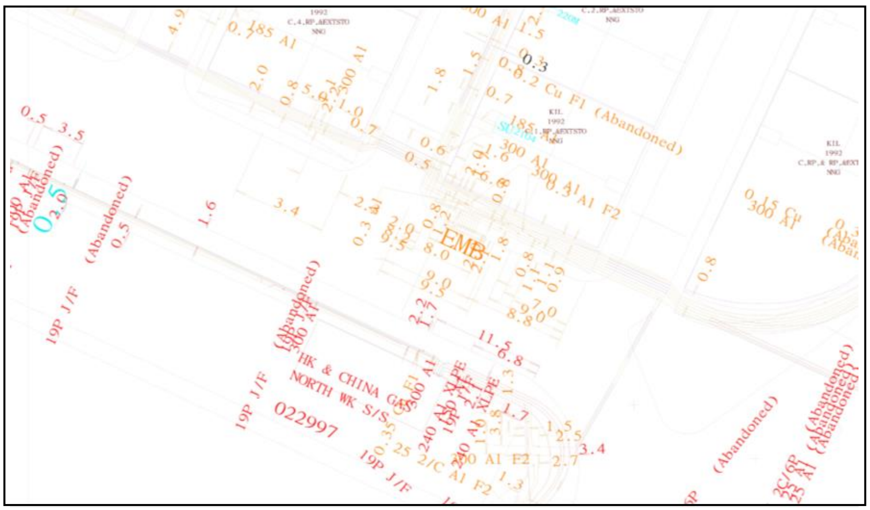


Figure 5 Electricity cable drawings and labels

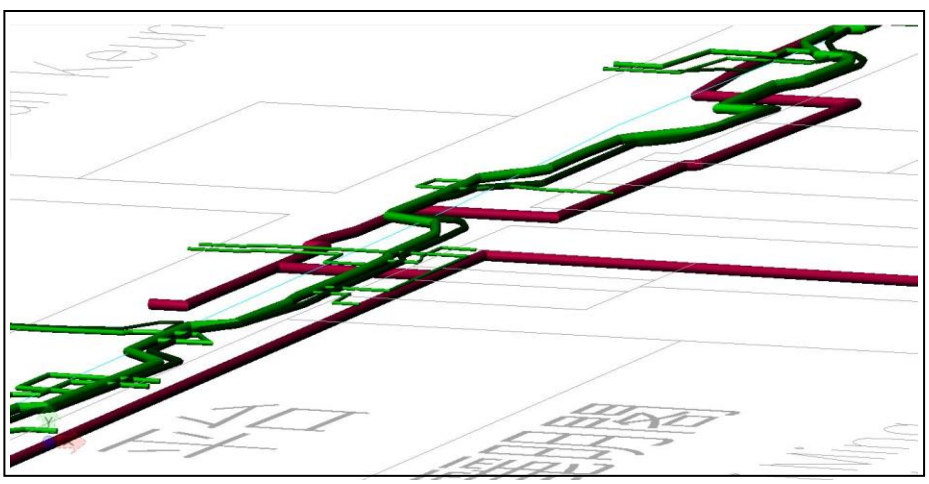


Figure 6 A 3-D view of several utility networks.

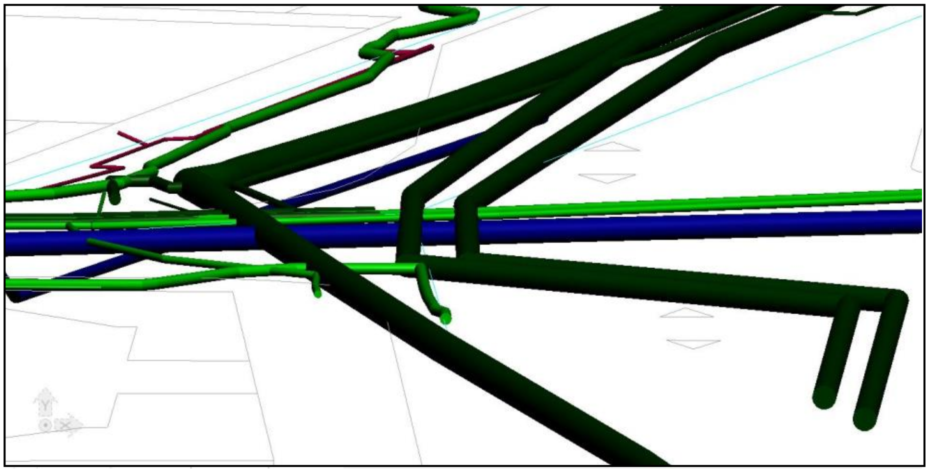


Figure 7 Problems with missing depth data for an integrated 3-D utility drawing.

Utility Type		**Fresh Water**	**Sewage**	**Drainage**	**Gas**	**Electricity**
Linear Feature		Pipe	Drain line	Drain line	Gas pipe, GIG pipe	Cable
Point Feature	Start	Pump	Terminal manhole connecting to buildings	Gully	Gas valve (on/off switch)	Substation
	End	Hydrant (street), Lateral Point (household)	Treatment plant	Outfall	Termination	Termination (household), Pole (lamp post)
	Intersect	Valves	Drain junction	Drain junction	Junction	Network junction

Table 1 Geo-database structure for the features and attributes