

Automatic generation of network schematics from cadastral databases: Applications for an electric utility company

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1. Introduction

ewz (Elektrizitätswerk der Stadt Zürich) is an electric utility company owned by the municipality of Zurich. The company's principal tasks lie in the production and in the distribution of electrical power. Additionally, ewz also provides energy-related services to selected customers. Thus, ewz provides about 220,000 customers in both the city of Zurich and in parts of the Grisons with electrical power. Besides, ewz also offers services for telecommunications infrastructure and currently establishes a city-wide fibre-optic cable network to provide all households in Zurich with high speed internet.

Utility companies such as ewz operate extensive distribution networks. It is of vital interest for the company to maintain proper documentation of these networks. As the supply zone of ewz is largely urban, constructions are mostly underground and thus not visible. Documentation of the network is hence a prerequisite for its protection, maintenance, and extension.

Specific Geographic Information System (GIS) solutions document the spatial aspects of the distribution network. However, there exist different aspects of the network that are represented (and hence visualised) each in specific ways (see Sections 2.2 and 2.3). The representations are often used in conjunction with each other when solving specific problems, such as planning the course of a new cable or locating the source of a failure. Paper print-outs remain the preferred work tool as they provide the best synoptic overlook. Printed plans excel in both unfavourable weather and dim lighting conditions and they allow easy manual re-editing.

Commonly, there are two different types of representations for the electric network's spatial layout (see Section 2 for details):

- *Cadastral databases* are detailed and integrated representations of the super- and subterranean in situ infrastructure.
- *Network schematics* contain selected and abstracted parts of the built situation. In contrast to a cadastral database map, a single geo-schematic shows the logical connections between the different components of one or several logical networks. This type of information is not apparent in the cadastral database.

Currently, the different databases are stored and updated separately. This redundancy leads to high efforts for updating. Equally problematic are discrepancies between the databases due to different update cycles. Thus, ewz and other power utility companies are interested to build an integrated solution. The goal is to automatically produce and update network schematics from the cadastral database. This process requires automated generalisation techniques for geographic abstraction.

The purpose of this paper is to engage the reader with this abstraction problem and open up a discussion about possible solutions rather than to present one. ewz seeks collaboration with a partner to elaborate an approach and work on a prototype solution for automated generalisation.

2. Graphic representations of power distribution networks

This section first introduces characteristics of a power distribution network that are relevant to the generalisation problem. The representations employed at ewz are then discussed, focusing on their graphic design. However, the representations are supported by data models that allow different types of computer-based analysis.

2.1 Characteristics of a power distribution network

Power transmission and distribution networks consist of a wealth of components. Besides the actual cables and joints, they include the containers of most cable terminals (e.g. substations, transformer stations, distribution boxes, house services, public lighting, etc.) and all components of the switch- and distribution arrays, including feeders, switchgear and bus-bars.

Objects such as transformer stations are not discussed in detail here, as they are usually represented as symbols, with their internal details hidden (however, electric schematics of the stations are stored in the cadastral database and are linked to the outside world). The focus here lies on the actual lines, i.e. the cables and cable conduits (e.g. PVC tubes, cement U-blocks, etc.), as their respective schematisations remain a major challenge. A power distribution network may be composed of complex nested structures: For the exact routing of cables, bundles of lesser diameter conduits (sometimes containing pre-placed cables) are pulled into larger conduits. The cables themselves may then be pulled into any one of these tubes. On the outermost layer, assemblies of such conduits are placed in a duct bank (Figure 1).

Multiple circuits of different cable networks or tube networks may lie in the same duct bank. Separate voltage levels (or line themes) often correspond to separate logical networks. The different circuits may or may not be connectable to voltage transition components (e.g. transformers).

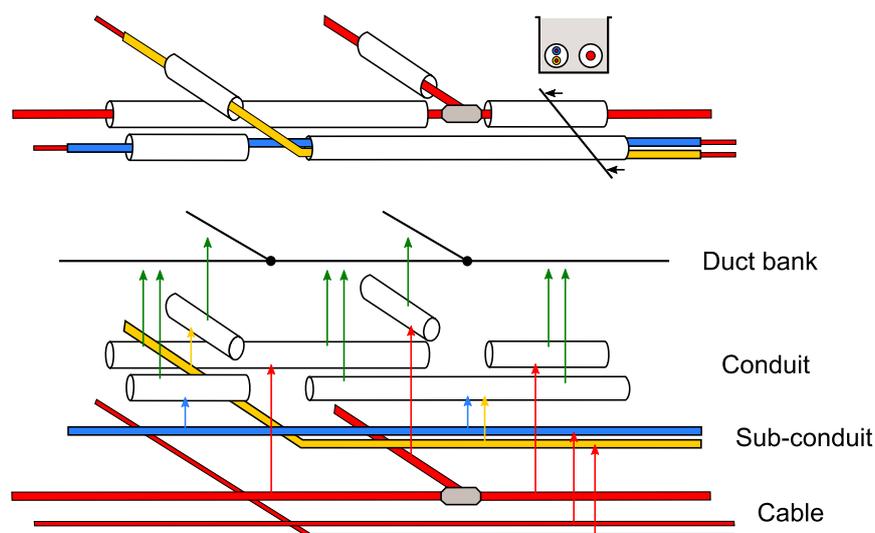


Figure 1. Hierarchy of duct bank components in a power distribution network.

2.2 Cadastral databases

Electrical cadastral GIS databases keep record of all in situ components of a power distribution network plus ancillary objects owned and maintained by the utility company. The target scale for ewz's cadastral maps is 1:200. Figure 2 shows an example extract of a cadastral map. Location and extent of the duct banks containing multiple conduits are depicted as red-outlined areas. The solid purple lines are courses of single conduit banks. The cadastral map also includes many other objects such as cable access vaults (black outlined boxes and circles), transformer stations and substations (not shown in Figure 2), public lighting (orange in Figure 2), etc.

Due to map scale constraints, ewz has renounced to show the nested structure of the power grid assemblies in the top-down view. As a consequence, ewz introduced numbered brackets across the bank representations. Each bracket number corresponds to a duct bank cross-section drawing which may be printed on a separate sheet of paper. Figure 3 shows an example of a typical cross-section. The cadastral database also holds electrical schematics of the internal situation of transformer stations and other objects that contain a substantial amount of electrical innards. Details about this part of logical networks are not considered in this article.

All objects in the database are interlinked with each other. It is hence possible to select a cable in a cross-section and track its course in the cadastral map. It is also possible to trace logical networks across objects, for example to simulate the consequence of a failure.

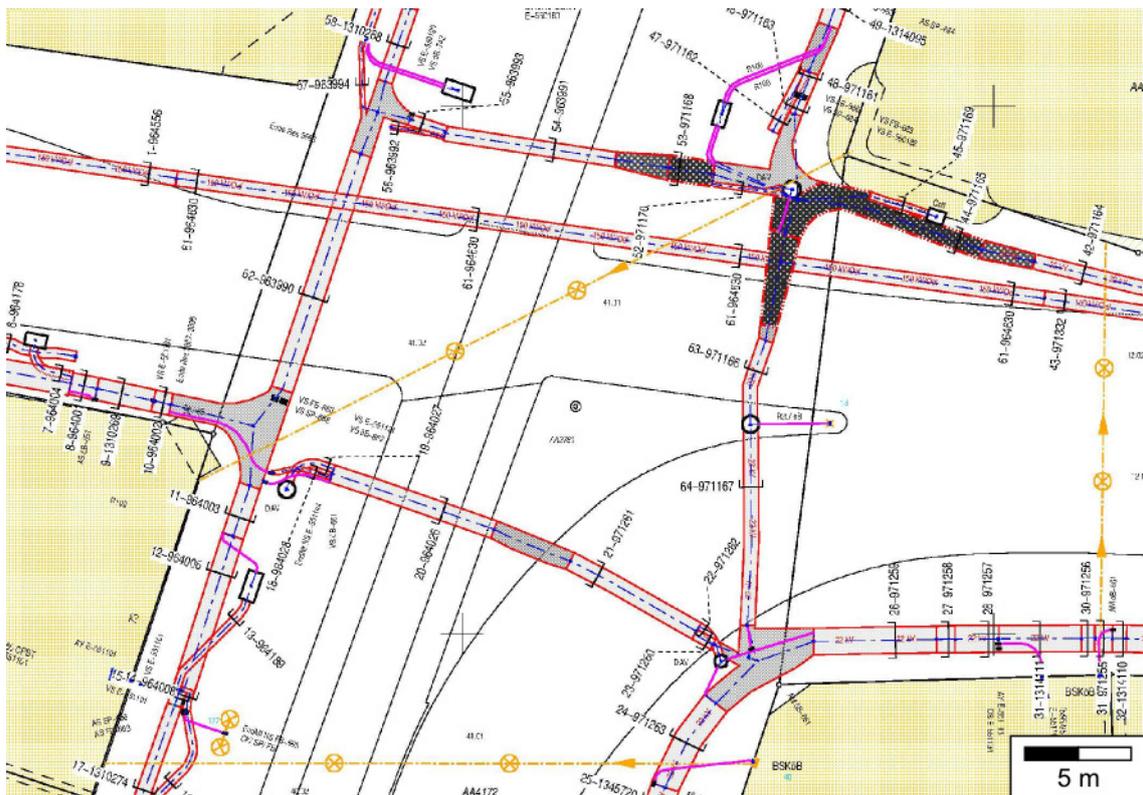


Figure 2. Example extract of the cadastral database maintained by ewz. Background map: © Amtliche Vermessung, Bewilligung Stadt Zürich, Geomatik + Vermessung, 20.06.2012.

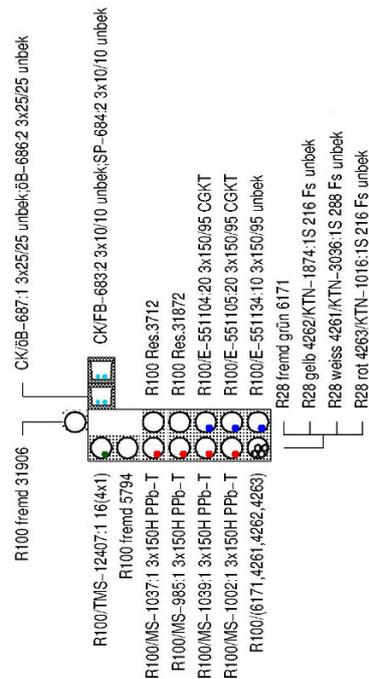


Figure 3. Cross-section view of an electrical duct bank with labels for both conduits and cables.

2.3 Network schematics

Electricity network schematics are synoptic representations of logical networks. At ewz, a scale drop from the 1:200 cadastral maps to 1:1,000 or 1:2,000 for the geo-schematic maps is usually applied. The schematic maps only contain features that are relevant to the logical network's schematic theme, i.e. most often the different voltage levels.

This way, a multitude of questions regarding the logical network may be answered with one quick glance. This is not really practical with just a map of the cadastral database since all courses of the different circuits lie on top of each other within the duct bank sections. Questions in the context of such applications are for example:

- How many cable routes are there between two transformer stations?
- Is there a through route of empty tubes between two stations that is suitable for the pulling in of a new cable?
- Which one is the optimal route from several available options for laying a new fibre-optic cable?
- What service area is powered by a transformer station?
- Are there redundant circuit links for supplying a specific maximum load?

Again for a clearer overlook, usually only one network schematic map is used to represent one logical network (e.g. the household voltage network). At ewz each theme or voltage level is represented and gets maintained in a separate schematic layer. Two examples of schematics are shown in Figures 4 and 5. Figure 4 shows an extract of the household voltage network (400V) schematic. This particular schematic comprises a rather comprehensive catalogue of features, but let us focus on the most important elements here. Each solid line represents a single electrical connection (circuit) between two elements (e.g., between the feeder of a transformer station and the feeder of a distribution box). Obviously, the cable aggregations of Figure 1 have been flattened in this schematic to allow the tracing of individual circuits. This results in

bundles of parallel lines that meet, cross, and split at certain locations, very similar to IC-board wiring. The large boxes in Figure 4 represent transformer stations; the lesser boxes represent distribution-boxes. The lines have been coloured according to their feeding power source. The label bundles contain both cable-type and circuit information. The type of map such as in Figure 4 is called geo-schematic since all depicted features maintain their approximate geographic location. This is in contrast to block- or orthogonal schematics that are usually highly abstracted.

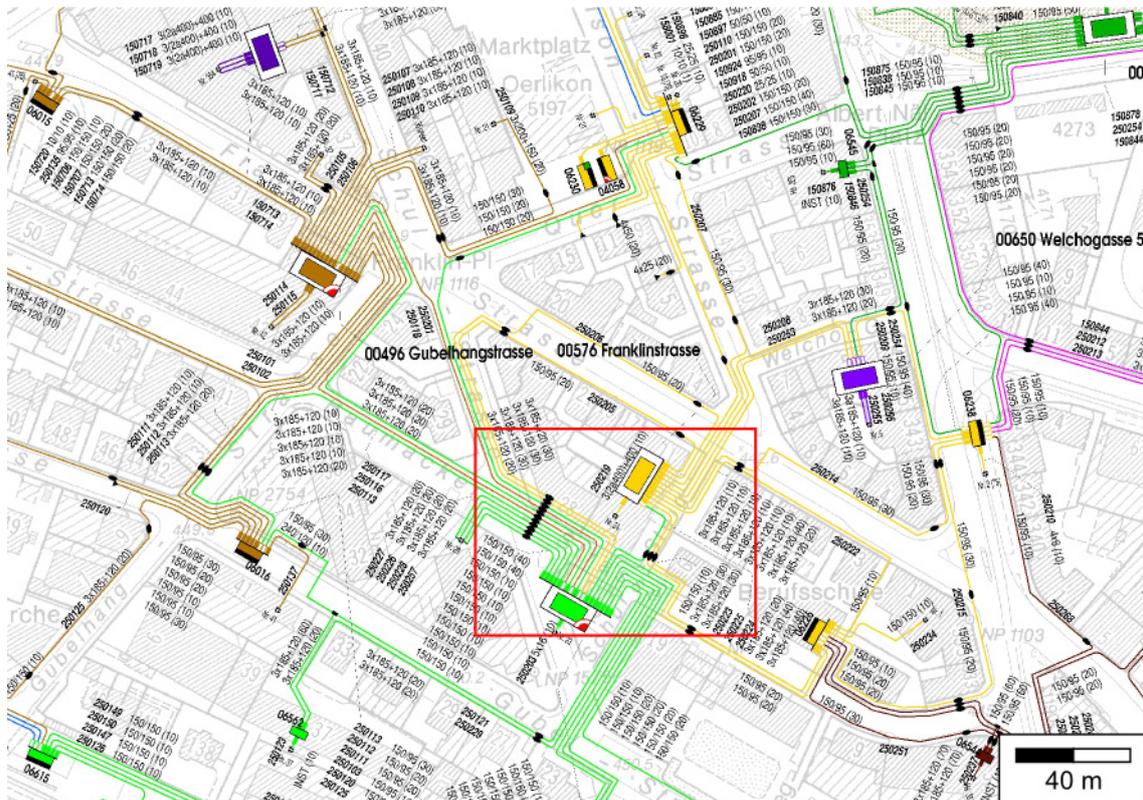


Figure 4. Schematic map of a household voltage (400V) network. Background map: Übersichtsplan Kanton Zürich. Reproduktionsbewilligung: Amt für Raumentwicklung, ZH 2012.016.

Figure 5 shows a completely different geo-schematic map representing the logical network of all those cable conduits that are either reserved for fibre-optic cables, or already contain them. Also shown are all those objects that contain terminals for those ducts.

This schematic is primarily used for the planning of new telecommunications routes and for finding potentially new duct connections between stations and sidewalk joint bays. The hierarchy between tubes is indicated by brackets across the lines.



Figure 5. Schematic map of all ducts reserved and used for fibre-optic cable installation. Background map: Übersichtsplan Kanton Zürich. Reproduktionsbewilligung: Amt für Raumentwicklung, ZH 2012.016.

Figure 6 shows a section of the cadastral database map. The extent corresponds to the red-outlined area in Figures 4 and 5. The situation in Figure 6 looks deceptively simple, but the content of the depicted banks form dense networks of parallel line swathes in the schematics around transformer stations and cable joint bays.

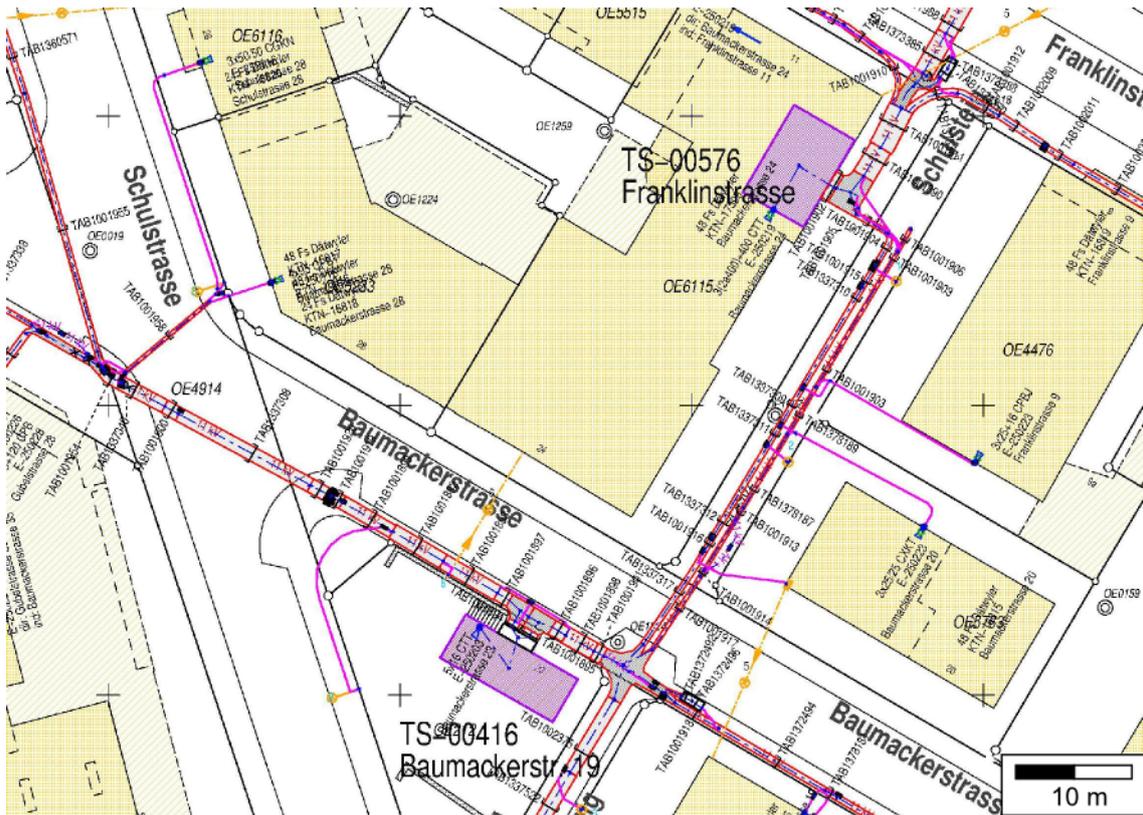


Figure 6. Extract of the cadastral map showing the area within the red rectangles in Figures 4 and 5. Background map: © Amtliche Vermessung, Bewilligung Stadt Zürich, Geomatik + Vermessung, 20.06.2012.

3. Automatic generation of geo-schematics

3.1 Process and required components

As stated in the introduction, the goal is to derive geo-schematics automatically from the cadastral database. This process is not strictly unidirectional, as there are occasions where a network schematic is updated without changing the cadastral database. For example, temporary elements that are installed in the power distribution network should be represented in the schematic for logical consistency, but not in the cadastral database. Thus, manual changes in the schematic should not be overwritten.

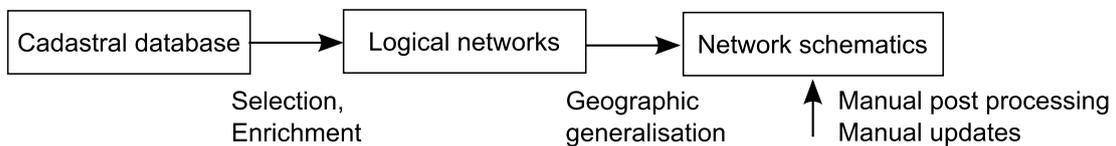


Figure 7. Process for deriving network schematics.

We have devised a two-step procedure for the derivation process (Figure 7). In the first step, thematic logical networks are extracted from the cadastral database. The decision to explicitly store logical networks was made to allow efficient analysis, for example to retrieve all service connections powered by a transformer feeder. In the second step, schematic representations are generated from a logical network, i.e. graphic representations optimised for a certain range of applications and a target scale. This

step now involves geographic generalisation. In the following, we will discuss the graphic transformations associated with the generation of network schematics.

Generation of line bundles

The nested structure of conduits and cables within a duct bank is flattened in a network schematic representation. Thus, linear elements that run within the same corridor in the cadastral database are represented as line bundles (see Figures 5 and 6). Maintaining readability of line courses imposes certain constraints. Lines are straightened and the course of nearby bundles is parallelised, and line crossings should be clearly visible. Manual post-processes of such line crossings impose a major effort within the current solution.

Displacement

The reduction in scale from 1:200 to 1:1,000 or 1:2,000 and the generation of line bundles result in a congestion of objects in areas with dense electric grid. Thus, individual objects have to be moved away from each other to create a clearly legible situation. Certain constraints guide the displacement of objects: Lines should remain placed on the same side of the road. Objects should be displaced to free areas of the background plan; in particular, building addresses should not be hidden.

Automated text placement

The solution also needs to support automated text placement. In Figure 5, for example, pipes are characterised by a pipe course identifier, the type of the pipe, its colour, and the usage. As can be seen in the figure, such texts take up a major part of the space available in the map.

3.2 Link to automated generalisation of topographic maps

How might the existing body of knowledge for automated generalisation of topographic maps help in the development of a geo-schematisation approach? The discussion above hopefully made clear that even if the theme is somewhat different, the problems for geo-schematisation are very similar to automated generalisation of topographic maps. It is hence foreseeable that a simple one-step procedure based on rules will not suffice, but that an iterative approach will be needed, which might be implemented as an agent-based model. It would also be interesting to explore whether an existing solution (e.g. for road generalisation) can be adapted to deal with electrical distribution networks.