GENERALIZED CARTOGRAPHIC AND SIMULTANEOUS REPRESENTATION OF UTILITY NETWORKS FOR DECISION-SUPPORT SYSTEMS AND CRISIS MANAGEMENT IN URBAN ENVIRONMENTS

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ABSTRACT:

Cartographic visualizations of crises are used to create a Common Operational Picture (COP) and enforce Situational Awareness by presenting relevant information to the involved actors. As nearly all crises affect geospatial entities, geo-data representations have to support location-specific analysis throughout the decision-making process. Meaningful cartographic presentation is needed for coordinating the activities of crisis manager in a highly dynamic situation, since operators' attention span and their spatial memories are limiting factors during the perception and interpretation process. Situational Awareness of operators in conjunction with a COP are key aspects in decision-making process and essential for making well thought-out and appropriate decisions. Considering utility networks as one of the most complex and particularly frequent required systems in urban environment, meaningful cartographic presentation of multiple utility networks with respect to disaster management do not exist. Therefore, an optimized visualization of utility infrastructure for emergency response procedures is proposed. The article will describe a conceptual approach on how to simplify, aggregate, and visualize multiple utility networks and their components to meet the requirements of the decision-making process and to support Situational Awareness.

1. INTRODUCTION AND MOTIVATION

Threat to life or physical condition due to natural catastrophes, international terrorism, power cuts etc. are a menace to our society that cannot be avoided. Major incidents or major crisis events require close and harmonized actions of affected organisations, institutions and participants in state, economy, and society. Quick response by decision makers is expected to get the situation under control, to avoid predicable secondary damage, and particularly to save lives. A common understanding of the current situation, occurring events, and processes is an absolute must in order to achieve coordinated action and to avoid misunderstandings. Quick grasp of crisis situation requires a restriction to minimum but essential information. Therefore, optimised cartographic visualizations have to be introduced to create a Common Operational Picture (COP - Steenbruggen et al., 2011) and enforce Situational Awareness (Endsley, 1995) by graphically presenting simplified and minimal maps that preserve the context and offer sufficient amount of information for crisis management. One of the most complex systems in urban environments are utility networks. Utilities are owned privately or publicly and therefore maintained by various companies, investors, or organisations responsible to guarantee publicly accessible supply of energy, electricity, natural gas, water, and sewage. Utility networks are explicitly considered as critical infrastructures since the facilities are of

"[…] significant importance for the governmental policy. Their failure or restrictions would yield sustainable supply shortages and crucial impacts on public security." (translated from (BMI, 2009, page 7)

Since public services are split between different suppliers, information on utility networks is not publicly available due to data protection or to keep it secret to competitors. Facts on age and condition of the distribution network and its technical components are generally not available as complete overview. This prevents a quick reaction in case of a network breakdown. The causes of failure of complex infrastructures are always varied and multi-dimensional. Intensive collaboration can prevent failure propagation, especially in the early phase of a crisis. It must be anticipated that a registered malfunction in one network can subsequently affect another. As much as it is difficult, it is necessary to communicate beyond one's own system boundaries. Successful coordination is an enormous challenge between organizations that are under time pressure, ignorant of the structure of neighbouring companies, and facing constantly changing conditions. Experience shows that even small malfunctions can cause significant problems at the interfaces between suppliers. However, each utility network is a highly complex system and even the cartographic representation of a single utility network is still a challenge. Visualizing multiple utility networks based on existing tools quickly reaches limitations in cognition and perception, which leads to substantial problems in sharing relevant information that is essential for achieving common situational aware-ness (Overbye and Raymond, 1999).

Events, such as the Italian blackout in 2003 or the interruption of power supply chains in wide parts of Europe in 2006, demonstrate the effects of infrastructure failures to society and the strong linkage of networks across borders. The outage of one infrastructure may influence others through a series of cascading effects (Becker et al., 2011; Becker et al., 2012). Therefore, infrastructure assets such as pipes, cables, and canals are particularly of interest in the decision-making process. Further damage or breakdowns at unforeseen locations may occur and require information of all utility networks and a

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holistic view for strategic crisis management. The challenge is to visualize the current scene including existing infrastructure that

- is suitable for handling disaster situations
- backs human beings' perception
- and is appropriate for reducing actors' stress level.

Visualization is a domain of cartography and consequently, maps for decision making have to be created that simplify and minimize network related information radically, while preserving as much information as possible. This paper will introduce an approach that explains how to simplify, aggregate, and visualize multiple utility networks and their components to meet the requirements of decision-making process and to support situational awareness.

2. COMMON OPERATIONAL PICTURE (COP) AND SITUATIONAL AWARENESS (SA)

Crisis requires the cooperation of individuals working together. According to Schmidt & Bannon (1992, page 7) cooperation is defined as

"multiple individuals working together in a conscious way in the same production process or in different but connected production processes.".

Computers, telephones, maps, paper, and pencils are used by actors to construct cognition and to enforce communication and coordination in crisis situations. To be able to bring actors to work in an orchestrated manner we need an understanding of

"how information is represented in the cognitive system and how representations are transformed, combined, and propagated through the system" (Hutchins, 1995, page 2).

A common understanding of the current crisis situation, occurring events, structures, processes and the available geodata is an absolute must in order to achieve coordinated action and to avoid misunderstandings (Becker et al., 2011). At first we need to identify the level of knowledge – well known as situation awareness, from the processes used to achieve that state. The Common Operational Picture (COP) forms the base for situation assessment to result in situational awareness. According to Endsley (1988, page 792):

"Situation Awareness is the perception of the elements in the environment within a volume of time and space, the comprehension of their meaning, and the projection of their status in the near future."

In conjunction with COP a common understanding of "what is going on" is needed and is handled as Situational Awareness (SA) in literature. For further information see Endsley (1995). The necessity of the COP (Steenbruggen et al., 2011) is not only found in a common visual presentation of the event site and its near surroundings but in the perception of the status, attributes, roles and dynamics of relevant features in the environment. Thus, some form of common understanding is interpreted and negotiated. On one hand, such COP enables the possibility to get needed information at the right time and in the right context by using maps, web services , etc. and on the other hand, it supports the decision making process in crisis situations.

3. INVESTIGATION OF EXISTING CARTOGRAPHIC REPRESENTATION

Investigations of existing utility networks in Berlin revealed that each utility network company uses its own cartographic representation for as-built documentation for maintenance and repair. Figure 1 highlights the issue that simply overlaying different network structures lead to graphical overload (Steinrücken, 2009; Bertin and Berg, 1983) and hinder identifying entities within the information process chain (Hopfstock, 2012).

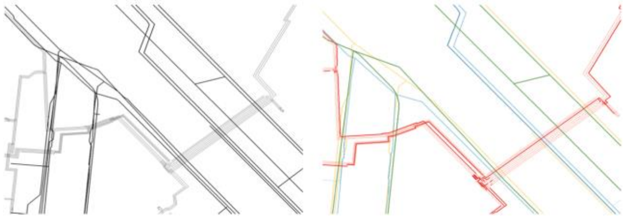

Figure 1. Cartographic Representation of multiple utility networks - uniformly (left) and systematically colourized (right) according to (RAL, 2001)

The visual perception of an object by location and type is the most important phase of map recognition; rapidness and reliability of perception, which is strongly related to density, and readability of map content.

3.1 Heterogeneity in utilities

Information exchange and re-use of infrastructure data is crucial to many utility organisations, especially in case of disaster, where different utility companies have to act together and synchronized to overcome the crisis. In disaster they require quick and efficient access to their assets in order to complete the SA and to generate the COP. However utility assets are held in different data systems, structures and data models. Beck et al (2008) classified the heterogeneities into syntactic, schematic and semantic heterogeneity (see fig 2).

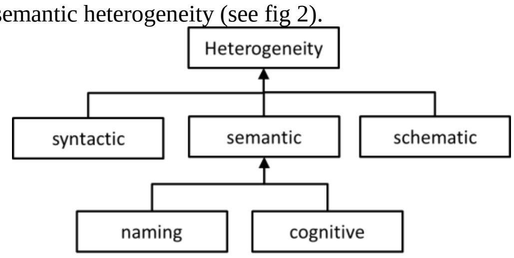

Figure 2. Heterogeneities in utilities

Syntactic heterogeneity refers to different data formats, whereas the same utility logic can be represented in different physical models, such as GML, ESRI Shape, etc. To overcome syntactic heterogeneity Service Oriented Architectures (SOA) are widely used to make utility assets interoperable.

Semantic heterogeneity refers to different naming conventions, conceptual groupings. According to Beck et al. semantic heterogeneity can be further subdivided into naming and cognitive heterogeneity. Naming heterogeneity occurs when semantically identical features are named differently. Cognitive heterogeneity arises when different utility features are named identically in different utility systems.

Finally schematic Heterogeneity refers to differences in data models between organisations.

To overcome the heterogeneity in utilities Becker et al (2011) defined a data model based on CityGML and GML to integrate different utilities into a city model and to provide one common homogeneous model for different utilities. This model forms the base for the following cartographic representation approach since it ensures the modelling of hierarchies, common semantics, topology and naming conventions. Thus the cartographic representation relies on a fundamental framework that can be used for representing all kinds of details and semantics for decision making process.

3.2 Visualization analysis

Anticipated to be an as-built documentation for maintenance and repair the cartographic representation uses colours, geometry, shapes and symbols to transform the real world object into map space. Those drawings are less suited for simultaneous representation of multiple utility networks and prevent prompt action in crisis situations. Thus, the common visualisation of urban objects and multi-utility networks lead to the issue that appropriate design schema for the representation of one utility network will become inapplicable in the context of representing multiple utility networks. Hence, a new cartographic design schema and related design rules have to be developed to meet the demands.

Applying simultaneous representation of multiple utility networks uniformly portrayed, as shown in figure 1 (left), prevent the perception of commodity types (pipes, assets, etc.), whereas figure 1 (right) enables the identification of different network hierarchies (red lines) as well as the network affiliation (yellow = gas, green = wastewater, blue = freshwater, red = district heat). Thus, for visual differentiation of utility networks colours are used to represent the transported commodity type. Different stroke width of linear features are used to emphasize the network hierarchy. In particular, colouration is widely used to encode distinct information but its usage is seen to be questionable due to their strong influence of human perception and cognitive load (Steinrücken, 2009; Bertin and Berg, 1983).

As shown in figure 3 (a-c) the map content changes radically when the scale is decreasing and the interpretation of the situation becomes difficult or even impossible. However, scales used in figure 3 are not suitable to enforce a common understanding of the crises situation. In preliminary tests (Semm et al., 2011) it turned out that the (min-imum) appropriate scale in crisis situations is 1:2000. At this scale disaster managers are able

- to identify required information
- to capture the common operational picture
- to plan coordinated action.

Figure 2 additionally indicates that very large scales are needed to meet the requirements of cartographic minimum dimension (Hake, 1995; Lechthaler and Stadler, 2006). In the scale range 1:800 to 1:150 the minimum dimensions and distances between linear objects were preserved, while for point objects the acceptable range is shifted from 1:300 to 1:60.

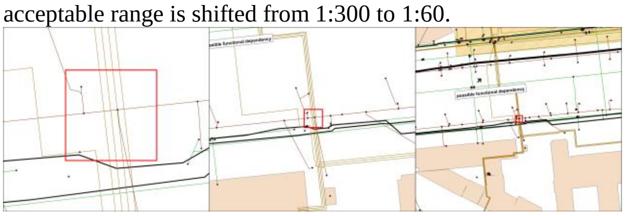

Figure 3. Object density at scales (from left (a) to right (c)) 1:60 (a); 1:300 (b); 1:800 (c) – lines are displayed by 1pt and points by 4pt (red square = 6m x 6m)

When smaller scales are used, relevant objects and relation information get lost. Clusters can induce superficial symbols when two or more symbols overlap each other. As a result, immediate scene perception is impossible and maps for decision making are not suitable. To overcome orientation and cluttered visualization issues different utility networks were investigated with respect to existing network hierarchies and functional equivalences, to be able to perform semantic and geometric generalisation.

3.3 Investigation on network hierarchies

SA and COP require a joint visualization of the needed information and objects with different spatial extents, e.g. overview, detailed view, etc. It was argued by Fairbairn (2001), that information is effectively deduced, transported, and refined when using different scale ranges for complex visualizations, i.e. small- (>1:20.000), meso- (1:20.000 to 1:6.000) and large scale (<1:6.000). Each range encodes unique and dedicated information (MacEachren, 2004; MacEachren et al., 2006), within this information process chain. Hopfstock (2012, page 55) states that

"the visual component of the data is used in the data supply chain so that the graphic presentation enables a communicative, map-based acquisition of geographic information that stimulates the visual reasoning of users and, ultimately, supports decision making".

The utility networks were investigated and analysed whether their elements are seen to be network-relevant or network-descriptive. Network-relevant objects represent the primary structure of each network, i.e. pipes, channels, tails ends, whereas network-descriptive elements represent objects that are not necessary for the on-going supply operation such as flange, corrosion measuring points, etc. Therefore, it was necessary:

- to identify the features to be displayed,
- to define the scale on which the data has to be displayed and
- to define a valid generalisation processes for map production.

Since this paper provides just a conceptual framework, we set the focus on the first two points. Readers interested in the generalisation processes are directed to Niel-sen and Meyers (2007), or Mackaness et al. (2007). By exploring and comparing the organizational and functional principles and structures of different utility network suppliers the investigation revealed that three main and distinct hierarchies are used. The network hierarchies for all analysed utilities can be distinguished into:

- H1 = transport lines, main lines, high pressure, excess voltage
- H2 = distribution, collection, medium pressure, high voltage
- H3 = house service lines, low pressure, low voltage.

All utility networks components such as pipes/channels, devices and setups can be assigned to one of these hierarchies and become comparable as well. Table 1 illustrates that different elements appear in multiple network hierarchies and multiple networks. Furthermore the figure indicates that a huge amount of objects have to be recognized and perceived by disaster managers during crises. Hence, a semantic generalisation in terms of qualitative generalisation has to be applied.

3.4 Investigation on functional equivalences

To support human vision and cognition in terms of rapid decision making, it was decided to provide knowledge of features' function type (semantic generalisation) rather than information about the diversity of network features. Insignificant information causes increased cognitive loads and graphical stress. Observable results cause troubles in (re-) cognition and association of objects, their role, and their relations. In crisis situations and under various stressors misinterpretation can happen, which prevents a common understanding of the situation. Caused by overload due to the enormous set of object classes, the operator might be overstrained to select the correct choice.

Table 1. Excerpt of functional equivalences across networks and hierarchies

Hierarchy	Element	Supplier
Shut-Off (function type)		
H1, H2	Slider	Fresh-water
H3	Valve	Fresh-water
H1, H2, H3	Valve	Gas
H1, H2	Valve	Long-Distance-H.
Vent (function type)		
H1, H2	Ventilation valve	Fresh-water
H1, H2	Deflation	Fresh-water
H1, H2	Shaft	Sewage-water
H1, H2	Ventilation	Long-Distance-H.
H1, H2	Deflation	Long-Distance-H.
Abstract (function type)		
H1, H2, H3	Hydrant	Fresh-water
Feed (function type)		
H1	Treatment plant	Fresh-water, Gas
H3	House	Sewage-water
Drain (Funcion type)		
H1, H2	Overflow	Sewage-water
Measure (function type)		
H1	Measurement contact	Fresh-water
Branch (function type)		
H1, H2, H3	Branch	Fresh-water
H3	Branch, connection point	Sewage-water
H1, H2, H3	Branch, connection point	Gas

A deeper insight into utility network drawings shows that a set of object classes could be identified representing a large amount of object variances that in many cases are just variations of standard functionalities. Knowing that objects are hierarchically structured we applied a classification and summarizing process resulting in seven top level classes as seen in table 1. A slider and a valve for example have the same functions; as for example, they open or cut off fresh water lines or gas pipes – the related function class is *Shut-off*.

4. CONCEPTUAL DESIGN FOR CARTOGRAPHIC REPRESENTATION OF MULTIPLE UTILITY NETWORKS

According to Fairbairn et al. (2001) cartographic representation has to consider the following aspects:

- what kind of data is to be represented
- the form of representation (analogue map, digital, etc.)
- purpose and target group of representation
- used technology.

Thus, a cartographic representation for actors in a crisis enforcing situational awareness and COP requires a joint visualization with different scale ranges, i.e. small-, meso- and large scale (Fairbairn et al., 2001). Each range encodes unique and dedicated information (MacEachren, 2004; MacEachren et al., 2005), within this information process chain. Thus, a new cartographic design schema and related design rules have to be developed to simplify the visualization radically, while preserving as much information as needed (Semm et al., 2012). Having a user-centered design in mind cognitive psychology plays a key role, since complex information has to be visually processed. When perceiving visual impressions, the cognition-chain involves various memory processes. Here, degrees of pre-knowledge and the existence of a common understanding play an important role concerning feature detection, template matching and symbolic description (MacEachren, 2004).

4.1 Reducing visual complexity and information density

The frequent occurrence of side-by-side or superimposed lines force an adequate differentiation and a partial shift of the geometric representation in terms of a generalized displacement. In contrast to land management maps that include precise locations and dimensions of subsurface features, a disaster management map has to mainly outline the overall situation of the area of interest and depict the functional dependencies between the different utility networks. Subsequently, it was decided to design maps applying cartographic procedures by generalizing, aggregating and simplifying the information important for disaster management, allowing a target-oriented analysis aiming to support coordinated activity (MacEachren, 2005). In this context, spatial and semantic generalisation plays an important role.
In order to obtain an optimal network representation several steps are proposed:

- directional simplification
- line aggregation
- symbol aggregation.

Throughout the first step, curved lines are straightened and restricted to horizontal, vertical and 45° directions. Since angular peculiarities are selectively processed by the human‘s brain, objects of equal angular peculiarity are cognitively grouped (Heeley and Buchanan-Smith, 1997; Vogels and Orban, 1985), which leads to a structured, methodical, and easier perceptible representation as illustrated in figure 4. This approach is similar to the design of metro maps as presented by Avelar and Hurni (2006), and Cabello et al. (2005).

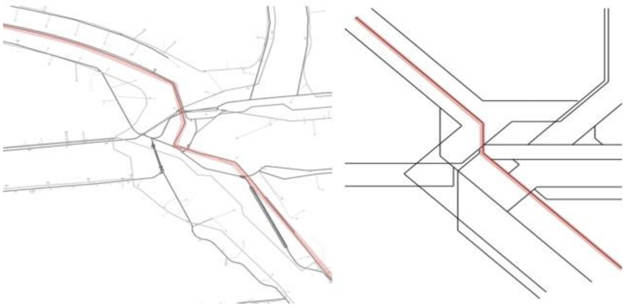

Figure 4. Comparison of network representations using original geodata (left) and schematic abstraction (right)

Although geometry has changed, the topology of the original information is preserved. Such representations are well-known as plane and near-plane graphs (Wolff, 2013). However, the design rules discussed by Avelar and Hurni (2006) are not fully applicable to multiple utility networks because:

- pipes or lines of two or more networks must not share the same direction and
- they must not share any start, end or intermediate node.

Hence, utility networks should be made comparable by generalization and aggregation of lines and network components on a semantic and geometric level. In order to distinguish between the different networks each obtains a unique colour in accordance to the well-known and standardized RAL-colours (RAL, 2001 - see figure 4).

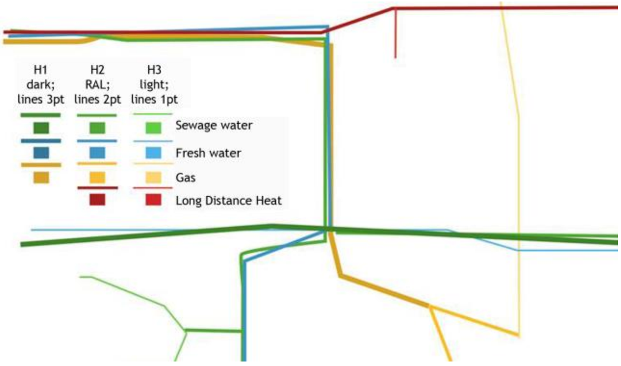

Figure 5. Functional equivalences across networks and hierarchies

Based on the classes defined in table 1 the functional equivalence of objects across multiple networks (like slider and valve that are classified as Shut-off) should also be recognizable. For that purpose dark / thick lines are used to point out the importance for objects of higher relevance / hierarchy, meanwhile, light / thin lines represent objects of minor importance. Those colour gradations are well known from cartographic design principles (Hake and Grünreich, 1994; Steinrücken, 2009). As illustrated in figure 5 this approach was applied to represent class H1 – H3 objects. Nevertheless, it is difficult to gain a quick overview, because lines are overlapping or get mixed up. Visual-textual association is prevented when objects lay in too close proximity or if thinner lines form bundles. In this case it is hard to identify the related line colour, due to colour mixture effects that influence each other (figure 4). Moreover, recognition of objects' hierarchy is difficult in these situations. In order to avoid these problems, line aggregates are formed that include a set of adjacent features such as pipes or channels. As rule for aggregation we propose that objects are merged if a buffer width of less than 1pt per scale type is reached, depending on the related hierarchy. This means that at a small scale all objects of H1 will be summarized within a buffer of 16 m - 4,8 m. Similar applies for meso-scale (1:20.000 to 1:6.000), whereas objects within a vicinity of 4,8 m to 0,64 m will be merged. Obviously aggregates reduce the number of objects, whilst preserving the needed object information. Aggregates were extended in their thickness and colourized with black, ensuring the highest level of graphical dominance. To preserve information about suppliers, colour-coded box annotations at defined intervals were added to the aggregated lines. Hierarchy can be expressed by variation of colour intensity (figure 6).

4.2 Providing simultaneous cartographic representation

As discussed in 3.3 seven objects' function types were identified during the investigation of relevant utility networks. It was identified that in each drawing, the different suppliers use their own symbols for objects' representation. These symbols are adjusted to their main purpose and were designed for as-built documentation, rather than for rapid cognition, as it is required for disaster management. In general, we cannot assume that decision makers responsible in crisis situations have deep knowledge of the symbols used by the different suppliers. This means that domain specific symbols may cause confusion or misinterpretation and a set of standardized symbols has to be designed that are associable, intuitive, and simple, in accordance with cartographic design principles (table 2)

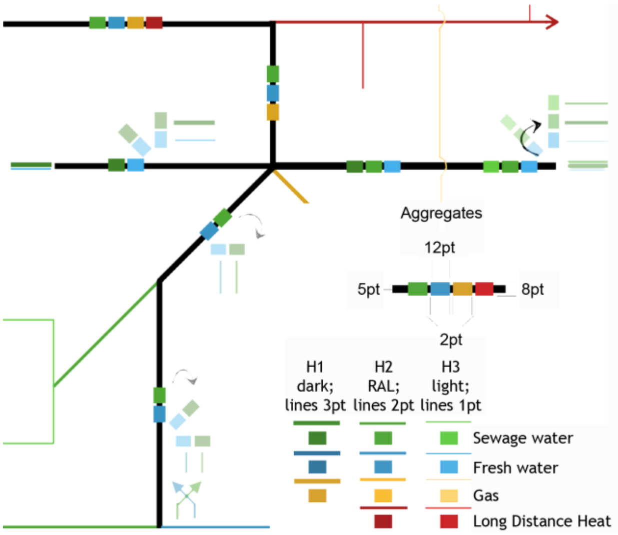

Figure 6. Reduced schematic representation of multi utility networks

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Table 2. Suppliers' and new designed common symbols for main functions

Fresh water	Sewage water	Gas	Long-distance-H.	Common Symbol
Shut-Off				
	-			
Vent				
	-			
Feed				
-	-	-		
Abstract				
Drain				
-		-	-	
Measure				
	-			
Branch				
-			-	

To implement the network overarching applicability of those symbols, they were designed to be graphically neutral using the colour grey.

4.3 Preserving information variety

Another important key aspect is the symbol placement. As you can see in figure 7 symbol overlap occurs in many cases that makes interpretation difficult. To solve this drawback, making the map legible, and express the spatial location of a network component, its initial position is replaced by a colour-coded point (figure 8). A point was chosen to ensure the graphical distinction of symbol placement and colour-boxes. This allows to maintain position, network, and hierarchy information for each symbol. Finally, the symbol can be placed so that an empty space of the map is filled. Graphical links between symbols of identical type (1: n relation) guarantee to keep the semantic connection between these objects and prevent insertion of unnecessary symbols. According to network affiliation and hierarchy, these links were colour-coded and dotted to make them distinguishable from line objects and were thinned to reduce their graphical dominance. In order to avoid misinterpretation, linking connection lines are not allowed to cross any lines representing pipes or channels. This means, qualitative as well as quantitative object information can be expressed by the amount of connection lines.

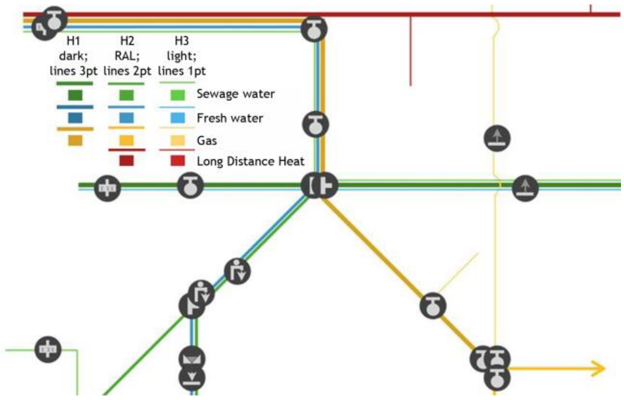

Figure 7. Representation of infrastructure following the metro map concept and the proposed symbolization

Based on the clearly arranged cartographic representation members of the decision-making groups can instantly get a general idea about the complex utility networks and their interdependency and will be able to focus on critical network sections where precautions and prompt action have to be taken to avoid subsequent damage.

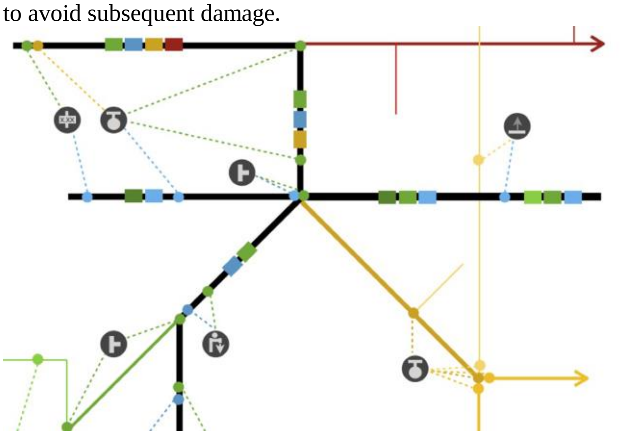

Figure 8. Proposed visualization for schematic abstracted lines and symbols with design elements, colour code, and dimensions

5. GENERALIZATION & AGGREGATION

In nowadays cartographic systems and GIS applications adjacency information between nodes (0-cell, where a cell is a connected subset), arcs (1-cell) and faces (2-cell) and solids (3-cell) is offered. With such information adjacent or neighboured features can be detected and algorithms can be developed that preserve the topological relationships during generalization and aggregation process (compare Ruas and Plazanet, 1996; Weibel, 1997a). For instance, if lines are adjacent to each other they can be aggregated onto a major line. Preserving the original network topology means, even by applying generalization and aggregation processes all features that are connected beforehand have to be connected as well after applying the processes. Generalization in this specific context means straightening lines, aggregation of parallel and neighboured lines - in general reducing the visual complexity of the scene in 2D cartographic representation as well as in 3D Scene view. Thus, a lot of operators can be applied that are well defined and formalized in literature (Robinson & Sale, 1969; Hake, 1975; Brassel, 1984; Butteneld, 1985; Nickerson & Freeman, 1986; Baumgartner, 1990; Plazanet, 1996; Weibel & Dutton, 1999, Cabello et al 2001, Cabello & van Krefeld 2002). However applying those operators means coming from a maintenance and documentation view provided by multiple sources into exactly one schematic representation of these networks. The challenge here is to combine these multiple networks together into one single schematic representation. A solution can be found in combining different utility network models into one single homogeneous data model as proposed by Becker et al (2011) or Beck et al (2008) and then applying adapted generalization and aggregation algorithms based on the network topology as it is proposed by Cabello et al (2001) and Cabello & van Krefeld (2002).

6. INTEGRATION AND HARMONIZATION OF INFRASTRUCTURES IN OUR URBAN ENVIRONMENT

The survey of existing GIS systems revealed that clear similarities between different kinds of infrastructure systems exist that allow the development of a homogeneous and common data model for all infrastructures. The diversity of network entities makes necessary the development of a data model that must be flexible and extendable. The Utility Network ADE of CityGML represents a first approach to extend the abstract model of a city by integrating utility infrastructures into the urban space and by making their network topology and topography explicit.

The core model (Becker et al. 2011) of this application domain extension establishes the relation, or – to be more precise – the connection between aboveground and belowground urban inventory with respect to utilities. The core of this ADE defines the modelling environment by making relevant features and their mutual relations explicit and allowing the 3D topographical modelling of entire networks, sub-networks and network features as well as their graph representations. The consequent treatment of network features as abstraction of real world objects (topographic point of view) as well as a graph object, represented by its own network graph, makes the model more flexible than the models realized in existing GIS utility systems. The module *NetworkComponent* (Becker et al., 2011) of the Utility Network ADE extends the core concept by classes that will describe the entities of any utility network in a semantical-functional way. The possibility of modelling materials, commodity types, and the full interior of pipes and tubes, makes the data model almost complete. The decision to extend CityGML by utility networks will later enable the use of standardized services such as WFS, WMS and W3DS and it will give others the possibility of further extending the model.

The developed data model was brought into practice within the project SIMKAS-3D. The aim was to develop methods for the identification and analysis of the mutual interdependencies of critical infrastructures, including the simulation of cascading effects in the failure of supply infrastructures (see Becker et al. (2011) for more details on the background).

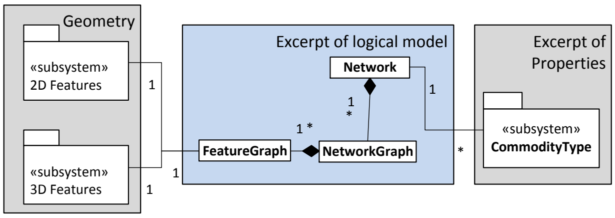

Figure 9. Implementation of the CityGML Utility Network ADE as a geodatabase model for ESRI ArcGIS

In order to achieve the project goals a data model and geodatabase for the homogeneous representation of different utility networks such as water, gas, long-distance heating, and power supply was developed. The integrated database facilitates a common operational picture (COP) for disaster management as well as for the simulation of cascading effects in case of network failures.

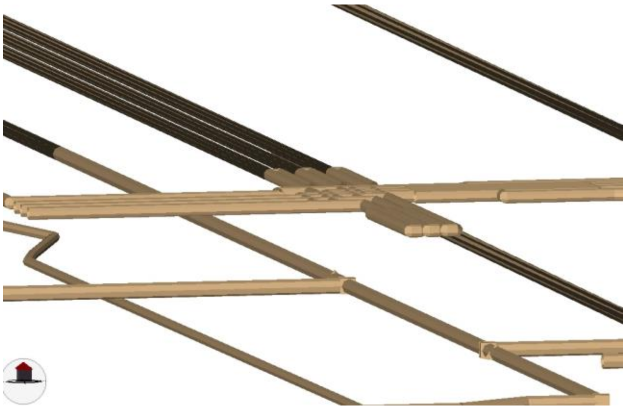

Figure 10. 3D visualization of heterogeneous utility networks in [FZKViewer]

The *NetworkCore* model, the *NetworkComponents* model, and the *NetworkProperties* model have been mapped to a relational database schema and are stored using the ESRI File-Geodatabase format. According to the three developed data models the database schema is partitioned into three major parts as well (see figure 9). One represents the geometry of the network components in 2D (polyline, point) and 3D (multipatch), one represents the logical model - the core model, in tables, and the last one represents the network properties (commodity types) as a relation to the networks. The utility networks of the supply companies were converted into the geodatabase by customized FME workbench processes. The proprietary GIS systems were the data source for the process and the created geodatabase has defined the destination writer type and schema.

Figure 10 depicts a 3D view onto multiple utility networks without any additional topographic informations based on the aforementioned CityGML UtilityNetworkADE. Without any topographic information it is hard to recognize the spatial location of that scene – the linkage to a specific point or location within the urban environment cannot be done. Moreover the 3D scene is faster overcrowded, cluttered and uninterpretable depending on the angle of view, observer point position (below ground, above ground, etc.). We need some landmarks within the utility scene that allows the linkage between position within the utility scene and the urban environment. Thus we require an approach that tackles the needed topographic information and enables a view in 2D / 3D that is not overcrowded and is interpretable for human beings.

7. DEALING WITH UTILITIES AND TOPOGRAPHY IN A 2D SCENE

In contrast to the already presented approaches Wolff (2013, pp 724ff) states, that geometric information of utility networks have to be integrated into a broader context. The superior spatial context is needed to support perception and cognition in terms of the data supply chain (Hopfstock, 2012) and is realized by cadastral maps, orthophotos or topographic maps. However, our topological correct abstraction of the reality loses information about objects' precise spatial location. This may impede quick orientation (Anderson, 2000; Artmann and Garbis, 1998) in many cases, especially for those who work in non-related fields. Once risk objects are identified, instantaneous action is required. Subsequently, the accurate spatial location is important, particularly with respect to action orders that have to be given to local task forces (see figure 11).

Figure 11. Arrangement of schematically represented utility networks and base maps (orthophoto left (figure 11 a); topographic map right (figure 11 b))

At least two solutions are proposed to tackle this problem, assuming that the related topographic maps are stored in the background:

1. In case the tool is implemented as an active system appropriate map information will be displayed on demand in auxiliary windows by a mouse click. For better orientation photos could also be added upon request. These maps and photos can be sent to on-site task forces for guidance if automatic control of utility network components is not possible.
2. In case the generalised utility map (schematic view) can be arranged above related base maps, such as topographic maps, orthophotos, or other thematic information. This implies that the utility map content will be graphically corrected to the underlying topographic or thematic information.

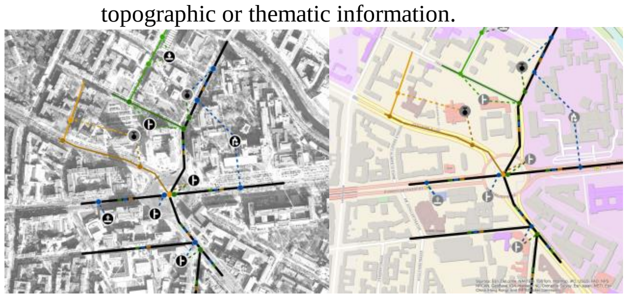

Figure 12. Redesigned (using center lines of streets as additional input) representation of overlaid utility networks on base maps (orthophoto left (figure 12 a); topographic map right (figure 12 b))

Moreover, the generalised utility network has to be adjusted to the spatially related geometry (figure 12). To avoid dominant appearance the background image shall be displayed with lower colour saturation or shaded in grey (figure 12 a).

8. DEALING WITH UTILITIES AND TOPOGRAPHY IN A 3D SCENE

As it can be seen in figure 13 the visual interdependencies between networks, network objects, as well as city objects were added. Figure 13 shows a 3D visualization of the available data and its embedding into the urban space. Each building of the dataset is logically connected to the available network. Thus, it is possible to perform complex analysis and simulations from producer (treatment plant) to the utility client (building) with respect to cascading effects, network tracing, and more.

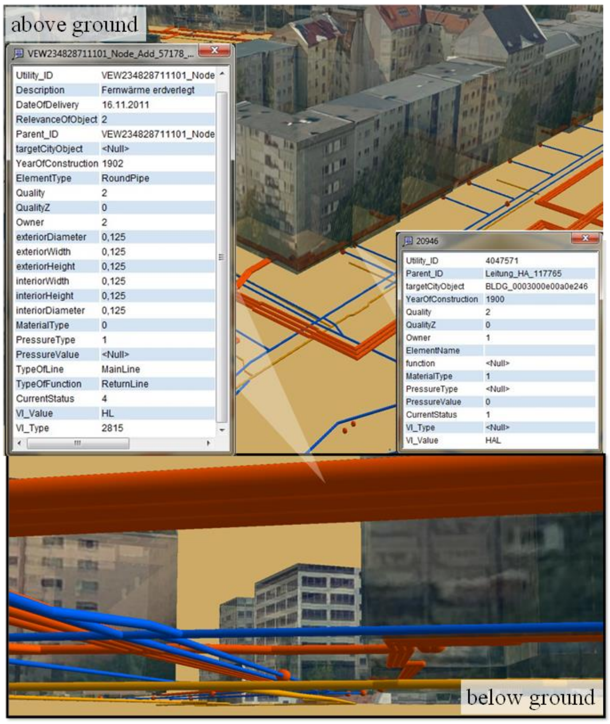

Figure 13. Embedded multi-utilities into 3D urban space in a perspective view (top = above ground; bottom = view from below ground)

However, as figure 13 shows as well, even by adding the linkage to the topography the scene is overcrowded and hardly readable and recognizable. Thus we need an approach that gives the actors in a crisis the possibilities to recognize the spatial location to get the linkage to the topography and the required information about the 3D position of their assets, the relation to other neighboured utility assets and detailed information about their assets.

9. DEALING WITH UTILITIES IN CRISIS

We propose a dynamic visualization approach that takes into account the network hierarchies, the related topography, and the network topology and creates dynamic visualization based on the observer view. This means depending on the distance between the observer point and the crisis scene either a 2D cartographic visualization is created or a 3D scene is presented for detailed information about the crisis hot spot. However both visualizations have to make use of the underlying network model presented by the UtilityNetworkADE and the included topology and hierarchy concept. This will ensure dynamic aggregation and generalization of the networks in 2D and 3D. The algorithms presented by Cabello et al (2002, 2005) have to be adapted to the UtilityNetwork model and to provide dynamic visualization in 2D and 3D. Furthermore the topography has to be included in the generalization process to provide topographically adapted visualizations of multi-utility networks in urban environments.

10. CONCLUSION AND FUTURE WORK

During a crisis response, various information sources have to be collected and combined by different stakeholders (Paton and Flin, 1999; Dransch, 2007). With this study, the authors propose a new type of holistic utility network representation that contributes to the assessment and accomplishment of crisis situations. Analysing drawings of four utility networks verified evidence that utility network maps of the different suppliers are of limited suitability in crisis situations. These drawings are mainly used for as-built documentation for maintenance and repair and do not allow for quick evaluation of how complex systems interact in case of emergency. It is difficult for involved actors to understand the interrelated system behaviour of utility networks when each company uses its own cartographic representation. The high amount of such detailed and complex information complicates clear and quick decision-making.
Therefore, the authors have presented a framework and a conceptual solution for the design and joint visualization of multiple utility networks and additional spatial information that supports crisis managers during the decision-making process. Challenging problems caused by violating cartographic minimum distances and dimensions were solved by semantic and geometric generalization. Information variances will be reduced to ensure legibility and perception. This has led to a map design for decision makers, which puts the focus on the main but essential network related information by simplifying, aggregating and classifying network components while preserving as much information as possible.

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