A PROTOTYPICAL SPATIAL DATABASE FOR MAINTENANCE MANAGEMENT FOR NETWORK TECHNICAL SYSTEMS: A CASE OF THE GAS SUPPLY SYSTEM

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Abstract: This article presents the results of research showing the use of GIS models developed by the author for supporting maintenance processes within gas supply system. Firstly the main maintenance problems appearing in the system has been characterized in the paper. On this basis the model of operational events handling, occurring in this kind of technical system, has been described. Author highlighted all stages in the model that demand information related to the location of the technical facilities in the terrain. This model is complemented by set of thematic layers created in GIS, which are useful during planning and realization of maintenance and repair works.

Key words: exploitation, network technical system, Geographic Information System, operational events, maintenance

1. Introduction

The gas supply system is one of the technical systems existing within the area of so-called municipal engineering. It consists of distribution pipes, compressor stations, underground tanks for gas and gas stations. The main task for the gas supply system is to satisfy the needs of customers in the supply of gas, which should have a sufficient amount of pressure and meet all quality requirements [3].

The specificity of exploitation the gas supporting system results from the following features of this system: large territorial dispersion of technical objects and limited access to pipelines and fittings, which in most cases are located under the ground.

In the case of the gas supply system there is no production understood in the classical way, that is why the main objective of the gas network management company is a reliable supply of gas to end users, which meets the required qualitative and quantitative criteria. Therefore, the maintenance of network system is a key area of technical operations for this type of enterprise.

Within the exploitation of the gas supply system currently there are used different kinds supporting tools. Three main groups of basic supporting tools can be identified [11]:

– first group consists of tools for records management of network technical objects as well as registration of carried out maintenance and repair works. This kind of software enables carrying out the technical, economical and organizational analyses, helping in network resource management and technical supporting for gas customers. In order to carry out these tasks, the most commonly are used ERP class systems (Enterprise Resource Planning) or CMMs (Computerized Maintenance Management system) / EAM (Enterprise Asset Management).
– the second group includes tools used to monitor the technical condition and operation of the network. These are Supervisory Control And Data Acquisition

systems (SCADA), which enable to run a full diagnostic supervision over the operation of the gas supply system. The tasks of network monitoring can be also conducted by intelligent systems and applications integrated with SCADA and GIS software [17, 18],

- in the third group are tools for the identification and spatial localization of technical objects within the network. This kind of tools are based on GIS technology (Geographic Information System), which in addition to the typical identification of network infrastructure on the maps it also enables support for decision-making process in the area of exploitation.

In this paper author focuses on the third group of the above mentioned supporting tools. It presents the proposal to use the GIS system to create a prototype spatial database, that allows the integration of data collected during the maintenance processes related to the gas supply system.

2. Overview of the main maintenance problems related to gas supply system

The most common problems associated with the maintenance of gas supply system are leaks occurring in gas pipelines and fittings. The maintenance for this type of operational events is performed at the base of the degree of risk, which determines the possibility of a gas explosion. There are three degrees characterising this risk [16]:

- first degree of explosion risk - are all, even small leaks, posing a direct threat to safety because of their location (adjacent to the basements or other underground installations). This category also includes large leaks that can appear on undeveloped areas. All leaks classified at this degree of explosion hazard must be removed immediately after their identification,
- second degree of explosion risk - are leakages through which passes more of the gas, but they occur away from other underground installations or buildings. Leaks of this type should be included in the repair plan and removed within a few days since their detection,
- third degree of explosion risk - are leakages through which passes a small amount of gas that does not pose a direct hazard to the environment.

The high standards of reliability and safety that are set for the gas network - require from the gas supply enterprise a wide range of activities that are aimed at: addressing the threat of explosion, proper maintenance and repairs carried out on gas network.

Scheduled maintenance and repair activities, related to the gas supply system, are performed according to the internal instructions set in the gas supply enterprise. This instructions are built at the basis of existing legislation and industry standards. The maintenance activities relate primarily to the following elements of gas supply system: gas stations in transmission and distribution, gas reduction stations, metering and billing stations, underground gas tanks, transmission networks and network fittings.

In the case of gas supply system the frequency of maintenance works is determined at the basis of their belonging to the category of hazard. The degree of explosion risk and the likelihood of leakage on the gas network as well as the possible consequences of this leakage are dependent on the following aspects: the gas pressure in the pipes, the specificity of the gas network, underground infrastructure density, the exposure of gas network to shocks caused both by traffic and mining works, and the technical condition of the gas network itself.

The degree of risk and the likelihood of leakage of gas pipelines depends on a number of external factors, which can be classified into four main groups [1, 6, 15]:

1. The first group of external factors that affect the gas network is corrosion. It can be the uniform corrosion as well as pitting corrosion. The intensity of corrosion depends on the type of soil and its moisture. The corrosion accelerates especially in the places where the pipeline insulation is damaged or where the micro-cracks exist (they can appear during the production process or as a result of improper transport of pipes to the construction site as well as during assembly the pipeline [7]).
   A very negative impact on the life of the pipeline have also the stray currents, which appear near the electrical traction [8]. They can be overcome by using an active cathodic protection and selecting appropriate protective coatings.
2. The second group of external factors are these caused by welding defects, defects in materials of pipes and fittings.
3. The third group of factors are the damages of gas pipelines and fittings - caused by external units or third party, which may be intentional (attempted theft, vandalism) or unintentional (accidents during excavation works). According to [15], approximately 50% of failure events associated with leaks of natural gas from pipelines constitute the mechanical damage caused by the activity of a third party. Fig. 1 shows an example of such damage, caused by an external company during trenchless drilling.

Fig. 1. Damage of gas pipe caused by an external company during trenchless drilling [5]

4. The fourth group of external factors consists of pipe damages occurring after ground movement caused by underground mining or through natural earthquakes. Damages to gas networks may also cause other natural disasters. The result of this type of failure are uncontrolled outflow of gas from the network [14], characterized by different intensity and which in extreme cases may lead to a gas explosion or fire.
   Fig. 2 shows an example of damage, caused by the mining impact.

Fig. 2. Damage of gas pipe caused by the mining impact [5]

Efficient detection of gas leakages is one of the most important tasks for maintenance services operating within the gas supply system. This is mainly due to the need to ensure the safety of the gas transport and distribution as well as the necessity to reduce the loss of gas, which adversely affect the financial results of the gas companies. Reducing leakage of natural gas also results from the environmental aspects, because natural gas is one of the main factors contributing to the greenhouse effect [2].

Leak detection of gas networks is performed during a routine inspections. Their frequency depends on the degree of explosion risk [16].

3. The possibility of using GIS system to support the maintenance activities within the gas supply system

Geographic information systems (GIS) are powerful software tools used for capture, storage, processing, visualization, analysis, and interpretation of spatial data forming spatial (geographical) database. The specificity of this software assumes that the objects presented on the maps contain spatial data, taking the form of models of real objects (lines, points, and surface objects - polygons) and descriptive data (stored in the tables of attributes associated directly with objects presented at the map). The functions available in GIS software allow to identify its main features, which include [9]:

– mechanisms for collection, storage and management of spatial data,
– analytic functions allow to carry out various analyses based on spatial relationships using data collected in the system,
– possibilities for visualization the results of analyses in the form of thematic maps, charts or drawings.

The main feature of such systems is the ability to create thematic layers, containing data presenting one type of object (ex. layers of underground networks, pressure reducing valves, meters, etc.). Each layer has a specific set of descriptive data (attributes) that are attached to all objects on that layer (ex. gas pipelines can have the following attributes: type of material, year of construction, the diameter of the pipe, etc.).

Complete information about the area took into consideration in analysis is obtained by overlaying of several layers characterizing variety of aspects. The different thematic layers can be displayed and analyzed individually or in combination with other layers, so the ability to hide the layers, not relevant to the particular analysis, gives a much greater transparency of the map. Layered structure model of thematic maps processed in GIS is illustrated in Figure 3.

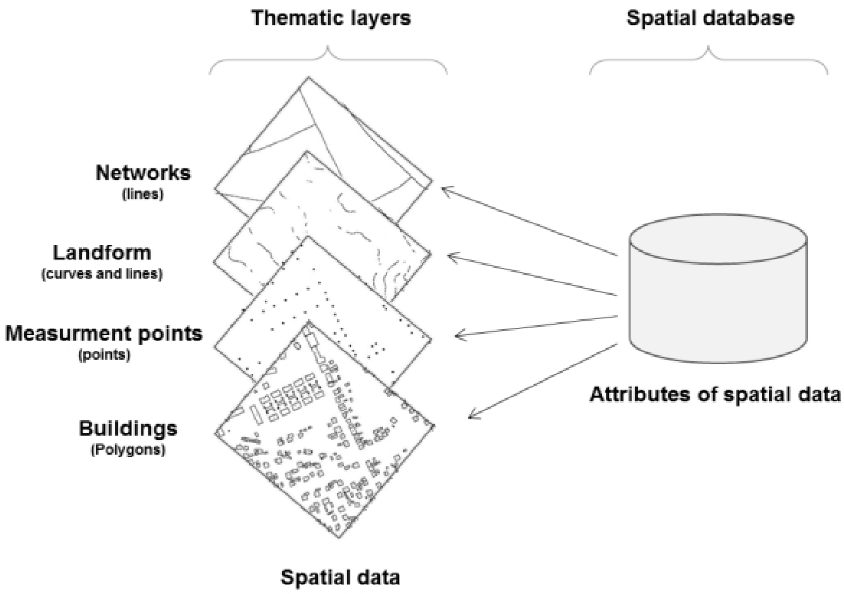

Fig. 3. Model of layered data structure on thematic layers [5]

Within maintenance management of the gas supply system, GIS software can be useful for supporting different kinds of exploitation tasks, which are carried out in the terrain. Fig. 4 presents the model of operational events handling process, which is related to the gas supply system. In particular, the model highlights all the points in this process, where the detailed information about the location of technical objects is demanded.

The process of operational events handling concerns both intended operational events (planned activities and operations, like inspection or maintenance works) and unintended operational events (failures on the network).

In the case of unintended operational events the first step is to identify the occurring problem. It can be registered as a result of the crash report provided by maintenance workers or notifications send by third party. The problems in the gas distribution system can be also pointed by SCADA alerts, which detect some irregularities in distribution processes. During this first step it is natural to get the information about localization of the registered problem and for that purpose the basic tool are digital maps stored in GIS (1).

In the next step, the information about failure is forwarded to maintenance crew (2). If the dispatcher doesn't have detailed information about the location of failure, getting this information will be the additional task for maintenance crew. In that case the digital maps provided by GIS are the primary source of information on the location of the gas supply network and its fittings.

At the stage of realization the repair order, digital maps provide information how to get to the place of failure and help to find exact technical objects (5). In the case of the intended operational events (planned maintenance and repair works), digital maps make it possible to create an adequate plan of inspection the gas network, including the sequence of technical activities in each points that should be inspected (4). Moreover GIS helps to plan the track of maintenance crew movement among inspected points.

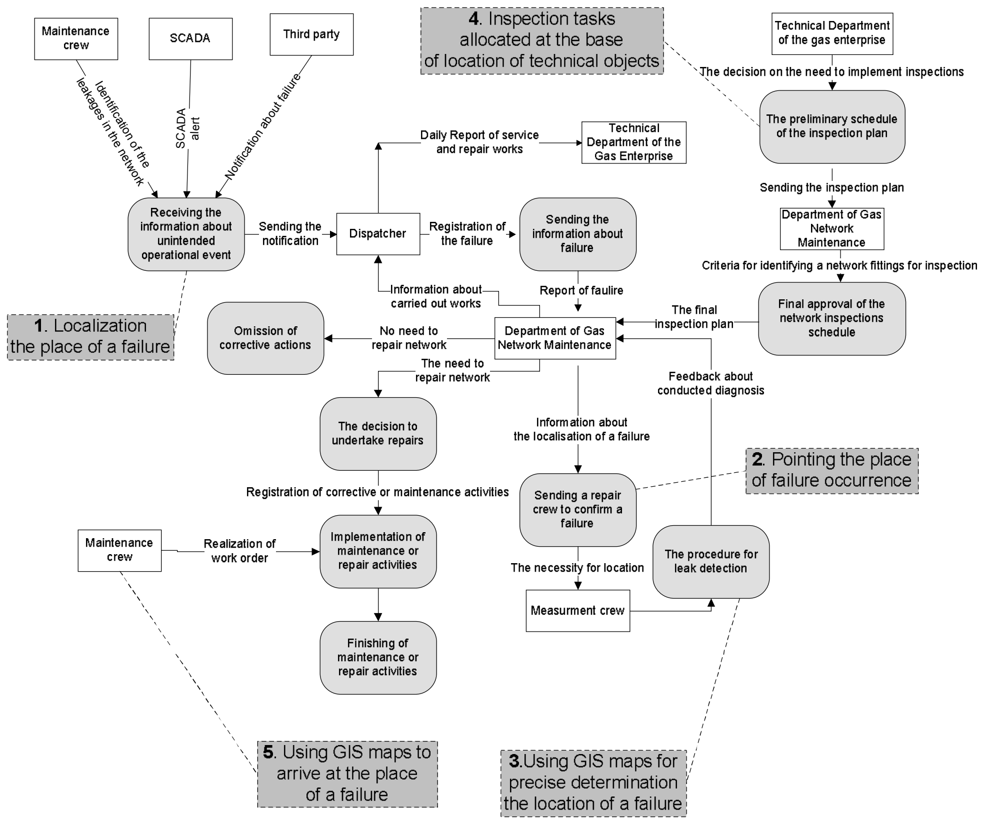

Fig. 4. The model of operational events handling process [5]

Besides aforementioned examples of using the information contained in GIS, a common area of using these tool is the identification the technical attributes of particular elements of the gas supply system - such as: the type of material, diameter of pipes, age of pipes, etc.. This information is important for planning maintenance and repair works as well as determines the type of required materials, equipment and tools that should be taken to destined place of exploitation activities.

Presented above examples of using GIS models in maintenance and repair works don't cover all the possibilities of support. Taking into account both the maintenance specificity of gas supply system and the number of external variables affecting the normal operation of the network, according to the author - the scope of using GIS should be much broader. The decision makers during the planning of maintenance and repair works should also take into account information about the external factors occurring in environment adjoining to the gas pipelines and technical objects [4]. Collecting this type of information on thematic layers in GIS allow decision makers to conduct spatial analyses, enabling efficient and rational scheduling maintenance or repair works.

This idea was an assumption for the development of thematic layers in GIS, designed to collect data on several aspects relevant to the management and operation of gas supply system.

4. A spatial database for supporting the maintenance management of gas supply system

As a result of research on maintenance processes carried out in the gas supply system [4, 5], three additional aspects has been identified as possible and reasonable for using GIS tools for their support:

- the registration of failures occurring in the gas supply system and analyses that can be done on that data,
- the evaluation of the technical condition that is focused on the individual elements included in the gas supply system. What is more the maintenance crews and quality of their work can also be the subject of such evaluation.
- identification and analyses of selected external factors affecting network failures.

For each of these areas author developed in GIS the prototype thematic layers for the collection of data characterizing these aspects.

4.1. Thematic layer „Failures”

According to author's assumption, the thematic layer "Failures" is created for collection and visualization on map the details of all the failures occurring in the gas network, along with their localization (dots on the map). Fig. 5 shows a fragment of this layer with the identification of descriptive attributes for the selected failure and photographic documentation made at the place of this operational event.

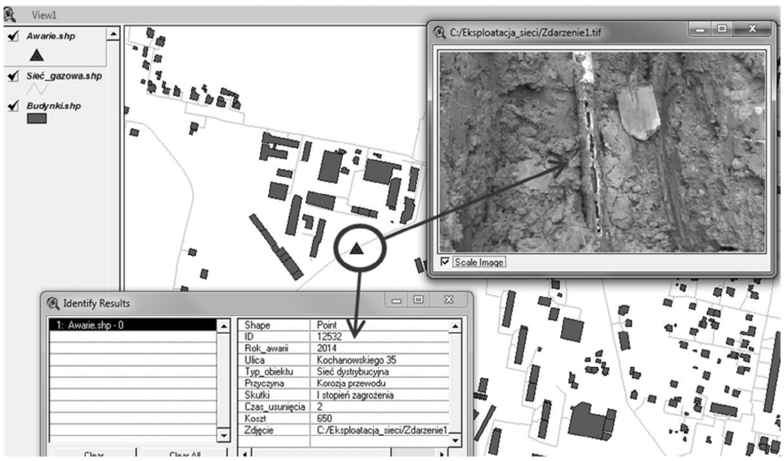

Fig. 5. An example of failure registered in thematic layer “Failures”

The starting point for defining the range of data collected within the "Failures" layer, was the analysis of information generated at the stage of repair works.

Basic information about all maintenance works are collected during the execution of work orders, which details are placed in CMMs system. Visualizing all the points characterizing the failures on the map and integrating them with the details of the breakdowns, costs of repairing, time spent on repairing works etc. - allow to conduct wide range of spatial analyses. These analyses may on the one hand help to find the causes of failures while on the other hand they may be useful for planning future inspections and preventive works.

4.2. Thematic layer „KPI indicators"

This layer shows the key performance indicators (KPI), characterizing the technical facilities connected with the network. The indicators may concern various aspects - from basic reliability indicators (MTBF, MFOT, MTTR, etc.), to the indicators characterizing the quality of maintenance and repair works carried out by the operational services as well as costs of these works [10, 12].

Indicators calculated for particular elements of the gas supply system can be displayed on the map, making it possible to immediately compare the different parts of the network in terms of chosen indicators.

4.3. Thematic layer „Mining impact"

The layer "Mining impact" presents information about areas, where underground infrastructure may be affected by ground movement. The layer collects and visualizes information about places where underground damages occurred as a result of mining collapses (Fig. 6).

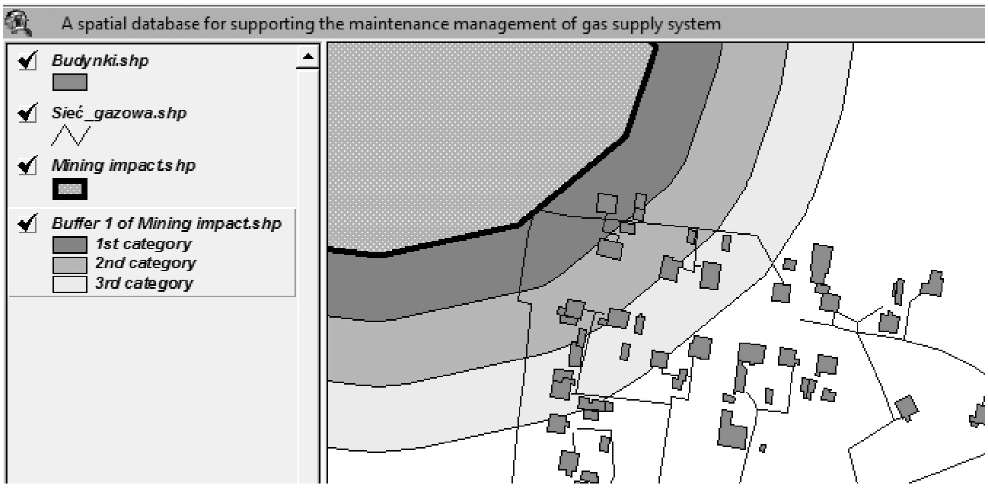

Fig. 6. The „Mining impact" layer

The attributes included in the "Mining impact" layer are obtained from relevant department of mining enterprise. Usually when some collapses occur underground - the information about this is immediately sent to all enterprises managing the network technical systems (ex. water supply enterprise, gas supply enterprise, etc.).

Typically this information is provided via telephone or fax and it includes the basic parameters of the underground collapse: the coordinates of shock epicenter, the force registered of shocks and the radius of their impact. This data can be used for visualizing the underground collapse on the map.

5. Spatial analyses using developed GIS models

In a typical approach data about various aspects of the gas supply network maintenance is usually collected in the form of paper reports or summary tables. This data is not directly applied to the place of its occurrence (on the map). By using thematic layers developed by the author the same data can be used for variety of spatial analyses that will allow to identify the important relationships between different factors. Without referring them to the land on which they occurred, it would not be possible. The results of this analyses may be useful for decision-making process.

An example of interesting spatial analysis using the collected data is shown in Fig. 7. The view presents basic maps of buildings and gas networks. These two thematic layers are standard in GIS systems used by gas supply enterprises. The other thematic layers displayed on the map are "Failures", "KPI indicators" and "Mining impact" and they include specific data detailed in sections 4.1-4.3.

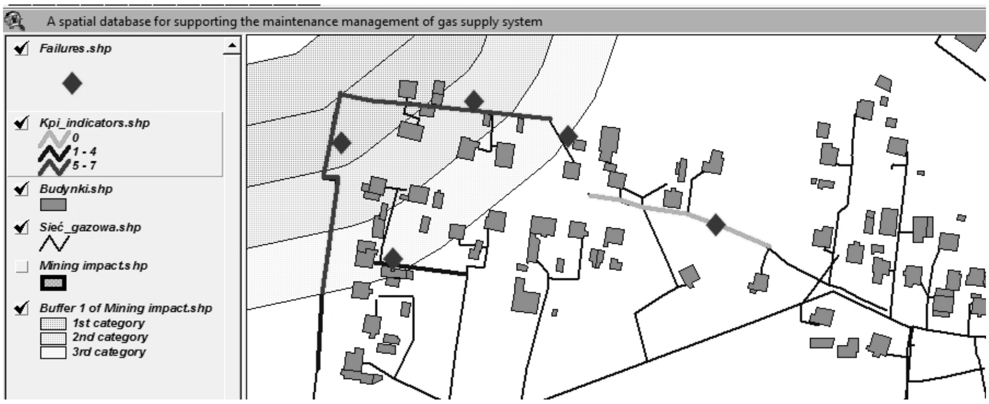

Fig. 7. Spatial analyses using developed thematic layers

Putting all of aforementioned layers in one view help to identify parts of the network and particular fittings, which are more susceptible to damage due to the external factors. When displaying "Mining impact" layer together with layers presenting gas networks and network fittings - it presents the areas where the facilities may be damaged - and suggest more attention for that technical objects during future inspection works. Similarly can be put together the "KPI indicators" layer related to technical objects and the "Failures" layer. The spatial analysis taking into account these two layers can help to identify the relationships between particular operational indicators characterizing the various parts of the network and failures occurring on these networks. Such analyses can help to identify areas with higher failure rates, which in turn allows to schedule adequate resources necessary to provide the proper level of maintenance service.

The detailed analysis of performance indicators in relation to the age of the pipelines, the type of material from which the pipes are made and local field conditions - allow to conclude on many aspects of the maintenance of gas networks. This kind of analyses allow to make better maintenance decisions.

The results of spatial analyses can be also adopted to future modelling of maintenance processes including scenario analyses of maintenance policies [13].

6. Summary

The results of research presented in this paper show the idea of a prototype spatial database with several of thematic layers created in GIS software. These layers can be used to perform different kinds of spatial analyses about variety of aspects concerning the gas supply system.

Analyses described in the paper show the possibilities for innovative supporting the decision-makers during stages of planning and the implementation of operational events handling. In order to perform such analyses in gas supply enterprises there is the necessity for appropriate procedures allowing to capture required data. When the proper data is collected then it can be used is wide range of spatial analyses in GIS software.

Examples presented in this paper show how the maintenance management can be supported with data collected within developed thematic layers of spatial database.

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