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Location Intelligence for Gas Transportation Infrastructure

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Due to the need for further expansion of a gas pipeline network and more efficient maintenance of available spatial data on the gas pipeline infrastructure, the management of gas transportation system operator has decided to extend the existing information system for the management of gas infrastructure by introducing location intelligence, i.e. its upgrading with the functional WebGIS solution. This paper describes the approach for developing the solution by using open source software components. The implemented WebGIS solution enables environmental monitoring in relation to safe natural gas transport, helps in planning and maintaining the gas pipeline network, and provides location-conscious decision-making on various aspects of the gas infrastructure management.

Keywords: location intelligence, gas transportation infrastructure, WebGIS, spatial data integration.

Inteligentne systemy informacji geograficznej wykorzystywane w infrastrukturze przesyłowej gazu

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Wzrastające zapotrzebowanie na kompleksowe i rozbudowane sieci przesyłowe gazu ziemnego oraz konieczność wprowadzenia bardziej wydajnego utrzymania danych przestrzennych dotyczących owej infrastruktury przesyłowej wpłynęły na podjęcie przez zarządcę infrastruktury decyzji o rozbudowie dotychczasowej infrastruktury o dodatkowe elementy związane z możliwością wykorzystania inteligentnych systemów lokalizacyjnych bądź odpowiednio rozbudowę istniejących elementów o rozwiązania funkcjonalne oparte na WebGIS.
W niniejszym artykule opisano podejście koncepcyjne omawianego rozwiązania z wykorzystaniem komponentów programistycznych typu open source. Wdrożone rozwiązanie WebGIS umożliwia monitorowanie

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bezpieczeństwa przesyłu gazu ziemnego oraz związanego z nim wpływu na środowisko naturalne, pomaga w planowaniu i utrzymaniu sieci przesyłowej oraz podnosi skuteczność podejmowania świadomych decyzji dotyczących różnych aspektów zarządzania infrastrukturą gazową w odniesieniu do aspektów lokalizacyjnych.

Słowa kluczowe: inteligentne systemy informacji geograficznej, inteligentne systemy lokalizacyjne, infrastruktura przesyłowa gazu, WebGIS, integracja danych przestrzennych.

JEL: C8, D8, L8, L9

1. Introduction

The Smart Distribution Network (SDN) is an intelligent gas distribution system concept that meets specific requirements and directly communicates with gas customers (Hiller, Koch, Schewe, Schwarz, & Schweiger, 2018; Costin, Adibfar, Hu, & Chen, 2018; Ashkezari, Hosseinzadeh, Chebli, & Albadi, 2018; Lu, 2011; de Castro Alves, & Manhães Gomes de Almeida, 2015). SDN can facilitate monitoring, control, and distribution management, while the geoinformation system (GIS) (Huissman & de By, 2009) provides the foundation for data needed to improve engineering analysis, asset management, and customer services. GIS can be used to specify the best location for sensors, communication cabinets, stations, etc. GIS also supports data management by allowing organizations to collect environmental data by desktops, servers, and mobile devices, and identify the relationship between the gas pipeline system and the environment. Gas distribution companies use GIS tools for advanced monitoring and modelling pipelines and studying the gas network connections. In this way, the system can represent the overall state of the network in a realistic model.

Maps are the most efficient tools for the visual presentation of spatial patterns. If they are carefully designed, they are more than decorative content and can help in asset management, maintenance and monitoring of infrastructure development, inspection of gas pipeline installations, and support of gas system security.

A geoinformation system with a unique spatial database would achieve rationalization, integration and optimization of decision-making across multiple sectors, as well as more efficient exchange of data across the organization. Data integration into a unique GIS creates better conditions for managing the infrastructure and the environment, making decisions, enforcing laws and regulations in the area of natural gas transport. A unique system also enhances the coordination and communication of all interested users by making them obliged to submit and exchange data within the system. This increases the availability, accuracy and reliability of data, and thus the quality of service delivery. Continuous data updates and exchange enable monitoring of changes primarily in the sectors of development and technical services, but also in other sectors, which ensures rational use and protection of the data.

The rest of this article is structured as follows: Section 2 provides background information on the case study including methods and goals of the research project. Section 3 elaborates on the methodology for location intelligence through the WebGIS solution. Section 4 discusses the results of the research project in relation to the used literature, and Section 5 presents the overall conclusion and offers recommendations for future work.

2. Introducing Location Intelligence

The public company BH-GAS doo Sarajevo was established by the Government of the Federation of Bosnia and Herzegovina in 1997 and is specialized in gas supply and operation of gas transport, distribution and storage systems. Its core business is the import of natural gas, its transportation and sales to large consumers (industry and gas distribution companies), and research and development related to the main gas pipeline network. As the gas transportation system operator in the Federation of Bosnia and Herzegovina (FBiH), this company is obliged to guarantee reliable and high-quality gas supply from the gas transportation system to the regulatory metering stations of local distribution system operators and end customers.

The organizational structure of this public enterprise includes the company assembly, supervisory board, board of auditors, management and the following 4 sectors for:

- technical services (transportation service and maintenance service),
- development,
- economic and financial affairs, and
- legal and general affairs.

BH-GAS manages the 16” (406 mm diameter) 169-km-long gas pipeline, and 6” (160 mm diameter) and 8” (219.1 mm diameter) gas pipelines with a length of 2.9 km and 17.2 km respectively. The company maintains the utility cadastre with coordinates and heights of gas pipelines per section. The geodetic maps used to maintain these data include cadastral plans in the scales of 1:5000, 1:2500, 1:1000 with horizontal and vertical representations and a topographic map in the scale of 1: 25000. All the above-mentioned layers are geocoded in the state coordinate system. Within a fifty-meter buffer around all sections of the main gas pipeline (406 mm diameter), all existing buildings (residential, business, infrastructural) are surveyed and vectorized. These data were collected during the construction and maintenance of the gas pipeline network. Geometric data sets are stored in the CAD (dwg) format, and attributes are stored in the Excel (xls) format.

In addition to the above-mentioned data sets, the sources of other data that can be used for the purposes of location intelligence are recognized:

- Cadastral data and digital orthophoto from the Federal Geodetic Administration (FGA),
- Urban and spatial plans from institutes for urbanism

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- A map of Bosnia and Herzegovina with general content: administrative and statistical spatial units, cities and settlements, significant objects, roads, rivers, altitude shows and other data sets from data supplier.

Assessment of the existing infrastructure showed that a unique GIS system for the organization was necessary for further information system development in the context of using existing spatial data sets.

The geoinformation system (GIS), as the key infrastructure component of location intelligence, provides a comprehensive and continuous overview of spatial information at the organization level. The visualization of the gas network managed by BH-Gas through a unique database was therefore one of the project tasks.

The main goal of the project was to enable spatial data presentation in real time, their intelligent analysis and search as well as full reporting with visualization via an online interactive map. This is achieved through the centralization of all available spatial data in the organization and access to spatial data of other institutions. In this regard, the solution is proposed as: “the centralization and integration of data and processes through a web-oriented spatial information system as an integral part of the BH-Gas information system”.

Based on the analysis of the existing state, it was concluded that implementation in the technical and development sectors should be a priority, while integration of the existing information systems and the GIS in the other sectors could be performed later.

The main reason for this conclusion is the fact that all spatial data to be used within the project come from these two sectors. The available geodetic plans and maps are georeferenced in the state coordinate system. The geometric data is updated regularly during the maintenance of existing gas pipelines and the construction of new ones. Due to updating the database, it is necessary to provide download data via the Federal Geodetic Administration web service. Similarly, data can also be exchanged with other institutions, such as municipal offices for urban planning, urban approvals and issuance of building permits.

The technical sector is responsible for maintaining the complete gas pipeline infrastructure including all overground and underground installations. The overground installations are monitored by regular periodic technical inspections and servicing, the underground installations are monitored by special methods of surveying the interior of the pipelines, so-called pigging. By introducing location intelligence, the editing functionality of cartographic layers is implemented through specially designed forms with drop-down menus, so that the state of the elements of the gas pipeline is indicated by the colour values on the map. It is necessary to provide data attribute entries as active (equipment name, type, conditions) and passive (catalogue, service data, spare parts) data sets. During the maintenance and control process for all built-in gas station elements, the database is updated with:

- records from specific infrastructure elements,
- the results of measurements for gas quality control on the chromatograph,
- data on the gas flow measurement device, and
- other available records.

Figure 1 shows the built-in elements at the gas station.

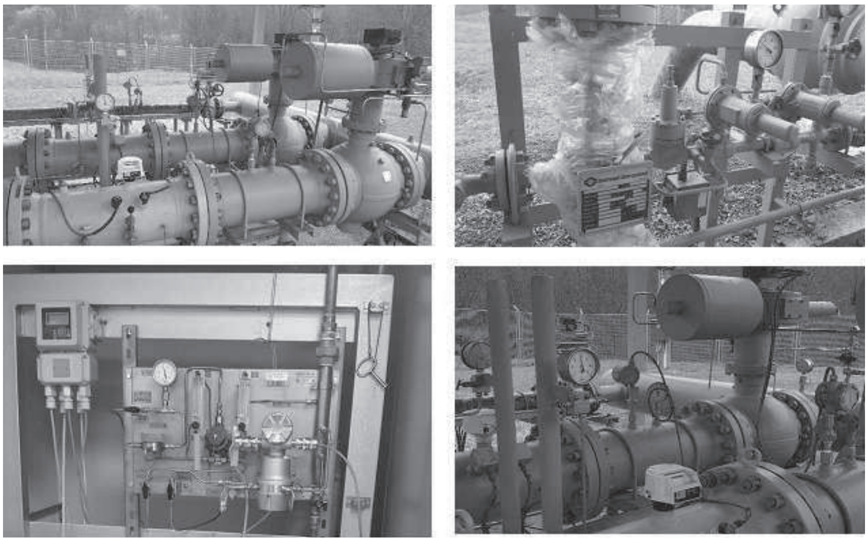

Fig. 1. Photographs of gas station elements. Taken by the authors.

In addition to the gas station elements, there are elements along the route (e.g. pipeline marks, milestones, etc.) whose data should be included in the GIS. Also, the data that are not used frequently and that exist in an analogue format are scanned and stored in the digital archive system as geocoded documents with metadata. Such documents can be spatially searched by selecting an MBR – minimum bounding rectangle (spatial query) – and filtered by key terms from documents or metadata sets. This mainly includes older project documentation (maps and drawings) in an analogue format used for the maintenance of the gas pipeline network. The technical sector uses a telemetry monitoring information system for dispatching. This system is connected by modems for telephone communication with the measuring equipment deployed along the pipeline network. Pressure and consumption information is simultaneously logged in an Excel table hourly and these logs are used to generate daily, monthly, and annual reports. It is possible to conduct various analytical operations on these data and generate ad-hoc reports whose results can be presented simultaneously and on demand in the GIS.

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The scope of activity of the development sector includes the planning and development of the transport gas system with the aim of meeting all the technical and economic requirements. This implies the development of conceptual solutions, the preparation of basic technical parameters of the gas transport system with accompanying facilities, the provision of technical solutions to the system management and the definition of the basic technical conditions and parameters for the preparation of the project task in the process of preparing tender documentation. This sector also participates in the development of technical regulations that can have an impact on the gas system, the formation of spatial energy zones as a function of the forecast of natural gas consumption, etc.

The geoinformation system ensures that all users from both the technical and development sectors simply and concurrently access the spatial data and update all relevant technical details on the pipeline elements needed to monitor the pipeline condition and maintenance. This primarily refers to an overview of existing and planned routes including the basic view of the axles, the protection zone, and drawn buildings in the vector format. By using the web services with cadastral data, existing and planned gas pipelines could be overlapped with cadastral and current ownership data for various spatial analyses and estimates of construction and maintenance costs. This information is also useful for other sectors (financial and legal) in terms of verification of the ownership status, usage rights, land value estimation, real estate sales contract preparation, land expropriation reports and other activities.

3. Methodology for Location Intelligence System Design

The implementation of WebGIS solutions, as a location intelligence system, includes the selection of geoinformation technologies, the development and integration of application solutions, the preparation and migration of data, and various accompanying services (e.g.: Becirspahic & Karabegović, 2015; Karabegovic & Ponjavic, 2012; Karabegovic & Ponjavic, 2010; Karabegovic, Ponjavic, Ferhatbegovic, & Karabegovic, 2018; Karabegovic, Ponjavic, & Konjic, 2003; Islam, Ahmad, Chohan, & Ashraf, 2015).

3.1. System Development

The system development implies activities to implement WebGIS solutions including establishing and maintaining a spatial database through the integration and centralization of spatial data, the development of an integral WebGIS application, the installation and customization of the system with user training and technical support. The implementation activities of the system included:

- modelling and reengineering of business processes (related to spatial data);

- functional and non-functional specifications development;
- system design including development of the system architecture, software architecture, data model, WebGIS application development and license installation;
- integration of data including extract, transform, load (ETL) (Kimball & Caserta, 2004; Han, Kamber, & Pei, 2011) of existing data, metadata entry and Web services;
- user and system administrator training, and system maintenance.

3.2. System Architecture

The platform for GIS development is based on the OpenGeo architecture (OpenGIS Architecture, 2018; Horvat, 2013) and uses different geotechnologies for creating an online internet map and building geoinformation infrastructure. The basis of this architecture are the functional layers of the system (Figure 2) for:

- presentation (user interface),
- application (logic), and
- data (databases).

OpenGeo, later Boundless, supported the development of many open-source software packages for the geospatial analysis, management and publication of geospatial information, like PostGIS, GeoServer, GeoWebCache, GeoExt, and OpenLayers.

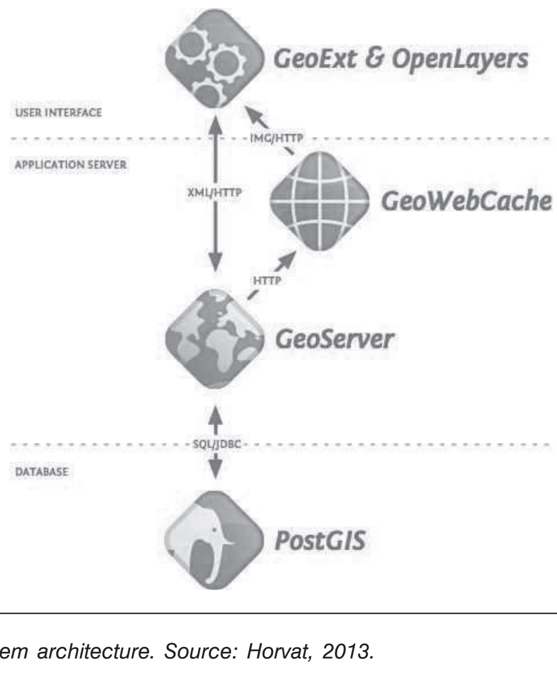

Fig. 2. The system architecture. Source: Horvat, 2013.

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During the project, it was announced that Boundless would stop updating compiled versions of Boundless Suite and the former OpenGeo Suite, and the Ubuntu repositories for these packages are no longer available. Boundless Server as open-source project is still available from the GitHub repo, but industry experts fast recognized that they could assemble all the pieces that make the "suite formerly known as OpenGeo" from various community projects such as Geoserver, Geoserver extensions, PostGIS, QGIS, QGIS Plugins, etc., which are all open-source. So, today OpenGeo lives as an unofficial set of open-source projects, but with the difference that the implementer needs to test and verify that the components work together properly.

The data layer uses PostgreSQL DBMS with the PostGIS extension. PostgreSQL is an open-source object-relational database management system. It uses SQL for data retrieval and can use most script programming languages such as Perl, Python, and Ruby. PL/pgSQL as the embedded language contains almost all features defined by the SQL:2008 standard and is the most complete open-source relational database. PostgreSQL does not support spatial data management, but a PostGIS plug-in is the solution. PostGIS functions are in accordance with the OpenGIS specification "Simple Features Specification for SQL".

GeoServer is selected as a server that could generate maps and control spatial data. Geoserver implements OGC standards – WMS, WFS and WCS. The user interface allows easily adding, updating, deleting data sources and layers, and setting styles (Figure 3). GeoServer uses the GeoWebCache – a tile cache server that speeds up the display of maps.

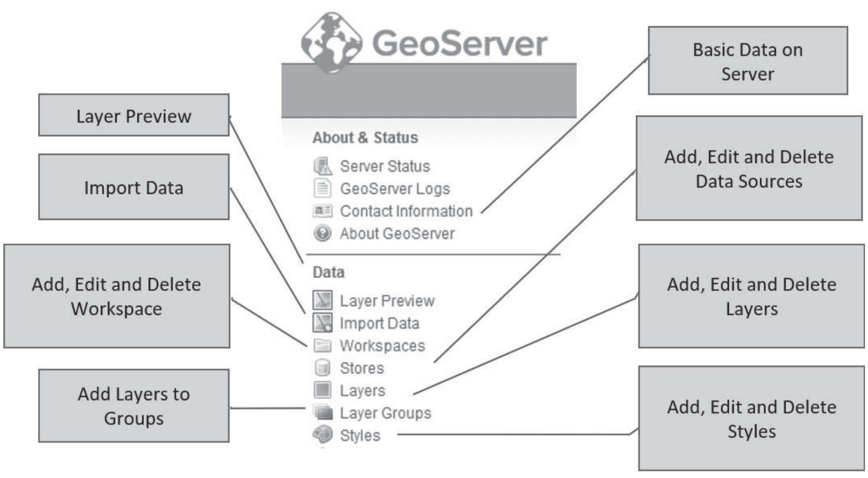

Fig. 3. Functionality and user interface of the GeoServer. Source: Public company BH-GAS doo Sarajevo. Retrieved on 6 January 2019 from http://www.bh-gas.ba.

For front-end application development (Figure 2), OpenLayers is used as a JavaScript library for browsing and interacting with spatial data using a web browser. OpenLayers enables easy integration with public web services. Another component is the GeoExt – a JavaScript framework for building rich web applications. Rich web applications are applications that need to have the same functionality as desktop applications, while their presentation runs entirely through web browsers.

3.3. Data Model

The purpose of the data model is to include by means of one document three essential data components used in workflow processes and process models: attributes, relationships, and behaviour. Data modelling is a critical task in the early phase of the development of an information system, which is particularly emphasized when integrating spatial data. It is essential that all geometric, topological and descriptive data are located within a logical model implemented in a unique spatial DBMS environment. This will ensure complete integration of spatial and other data and their use through GIS and other applications. The proposed model of geometric and attribute data of the gas pipeline network is in line with the official model of the Real Estate Cadastre Database for Bosnia and Herzegovina (BiH), as well as with the Utility Cadastre Data Model for FBiH (Utility Cadastre Data Model for FBiH, 2019).

The geometric data model is based on available geometric types of the GML 3.1.1. standardized geometric data model (spatial topology), as well as associated complex types that enable the maintenance of GIS data using time domain (time topology) according to ISO 19107: 2003 (Geographic information – Spatial schema) and ISO 19108: 2002 (Geographic information – Temporal schema). It uses the Feature Data Objects (FDOs) for the implementation as the basis for a standardized classification of graphic and non-graphic data, while respecting the OpenGIS specification which describes the implementation of the data collection interface and data formats in detail, in addition to aligning them with current technologies.

3.4. Web Services

The use of LI and GIS to manage the infrastructure of gas transport results in human, material and financial resources savings and improves management effectiveness. It is possible to fully utilize the existing equipment, software and data, and minimize system recovery. In this sense, what is envisaged is the integration of internal subsystems via web service, as well as the presentation of a live data set from the SCADA system using web maps with appropriate themes (Lu, 2011).

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Additionally, Web services imply data use through the Web Map Service (WMS) or Web Feature Service (WFS) protocols. This project envisages the use of the most popular free data services, such as MS Bing and Open Street Map. Also, standardized commercial web services of the Spatial Data Infrastructure (IPP) of FBiH offered by the Federal Geodetic Administration (Federal Geodetic Administration web services, 2018) are implied.

3.5. Desktop Application

For the purposes of mass input and data editing, as well as for complex analytical operations, the open source QGIS tool was applied (Figure 4). QGIS is the standard for desktop cartography, visualization and geographic analysis. Direct read/write database capabilities through ODBC connectivity allow keeping all organization data up to date. This application allows the use of different file types (dxf, shapefile, etc.) as well as personal geospatial databases and web services that allow the use of external data sources (WMS, WFS and others).

Desktop users across the organization can connect to the central database and manage and exchange information between different services. The embedded conflict management mechanism ensures non-compliance data management when writing to the server. Each user can have access to vital intelligence information and use them for spatial analysis and decision making.

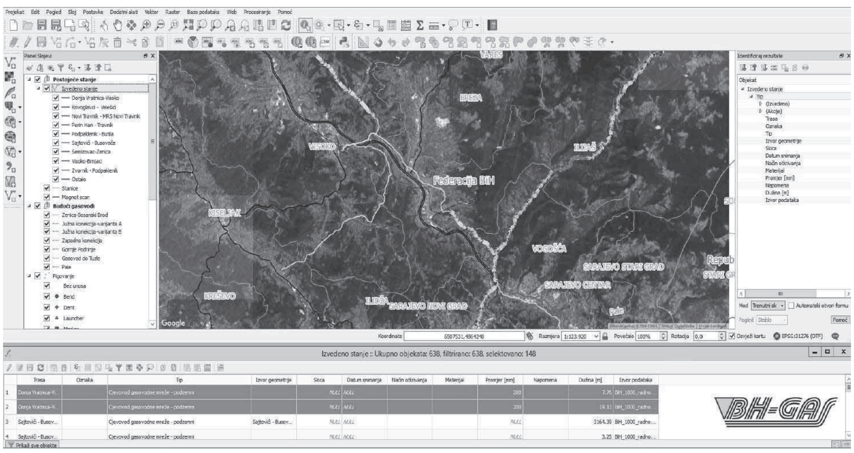

Fig. 4. QGIS desktop application for network analytical operations with gas pipeline data. Source: Public company BH-GAS doo Sarajevo. Retrieved on 6 January 2019 from http://www.bh-gas.ba.

3.6. Spatial Data Centralization, Integration and Presentation

Data centralization implies the collection, structuring and placement of existing sets of digital spatial data on a central server, or in a unique database, to provide data access and insight to all employees within the BH Gas organization.

The most important data are sets of georeferenced spatial data like:

- vector data related to gas network geometry,
- orthophotos,
- BiH map with basic cartographic content,
- spatial, urban and regulatory plans,
- digital terrain model,
- raster data of geodetic plans, and
- digital data model (20m).

User Interface (Figure 5) as a presentation component represents an integral part of the geoinformation system. In addition to presentation functionality, it helps to set up spatial queries, search and filter data, manipulate cartographic layers, draw and other operations with spatial and non-spatial data. To meet the needs of the technical maintenance and development services, the interface has been developed to support spatial information, map rendering, editing, queries and the necessary spatial data analysis of gas infrastructure (Klein, Kesl, Bhattacharya, & Abdullah, 2017; Azadeh, Salehi, & Salehi, 2016; Kazmi, Shahzad, Khan, & Shin, 2017).

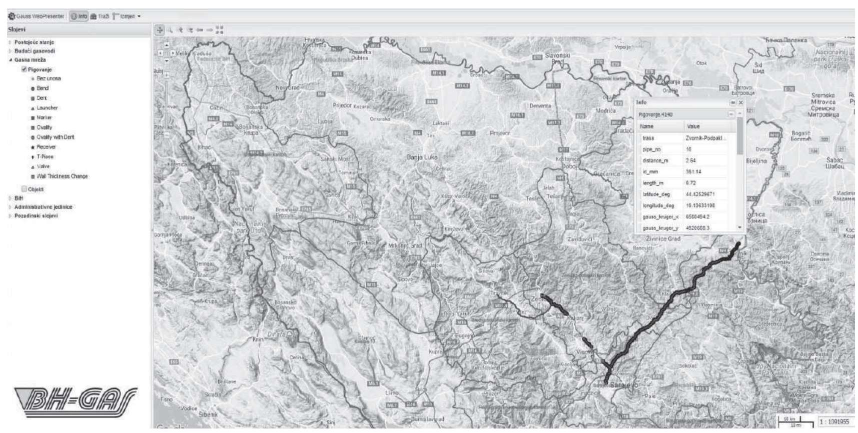

Fig. 5. User Interface of the Gas Infrastructure Management Application. Source: Public company BH-GAS doo Sarajevo. Retrieved on 6 January 2019 from http://www.bh-gas.ba.

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4. Discussion

By developing the geoinformation system for the needs of the BH Gas organization, the intent of introducing location intelligence (LI) was realized as a new paradigm of using spatial and non-spatial data. Also, more efficient information exchange and management between individual sectors are ensured. The main purpose of the WebGIS component was the presentation of spatial data to users at the organization level, including the dissemination of vector and raster data of the gas infrastructure, cartographic thematic data, and textual data with tables, diagrams and various documents. Feedback from the system is continuously provided to users who make decisions based on location intelligence. Through the WebGIS user interface, it is possible to search and select, distribute (view vector and raster data and download them in the Excel or PDF format), publish, administer, maintain spatial and non-spatial data relevant to the gas pipeline transport system.

Additionally, the application of web services providing official and up-to-date information from other organizations is ensured, enabling the overlap of gas pipelines with other expanded contextual data sets and their thematic, textual and geospatial search for defined areas of interest (AOI).

It is easier to administer the system by implementing the user rights definition tool, and tools for customizing and changing layout and content of the user interface. This set of administrator tools allows:

- making editorial changes of news and information;
- changing appearance, colour and font types;
- changing menus, dialog form and hierarchy of pages;
- managing user rights:
  - public users with limited access rights (search, selection, and review of data);
  - professional users (employees) with unlimited access rights; and
  - registered users (administrators) with unlimited access rights;
- system monitoring and reporting.

The development of all components of the system including the user interface, WebGIS application and database is realized in accordance with relevant international standards and guidelines (OpenGIS, ISO / TC 211, INSPIRE and others) and is based on a collection of software modules. In analyzing the literature, it was concluded that there are various trends of LI system upgrading noticeable in the market as well as in research projects. An example is the work by Hiller, Koch, Schewe, Schwarz, and Schweiger (2018) that represents the software solution for ForNe System (Forschungooperation Netzoptimierung), developed by the largest German distributor Open Grid Europe GmbH (OGE, then E.ON Gas Transport) and Zuse Institute Berlin. The solution is based on the Software-as-a-Service (SaaS) platform that provides various interfaces for data presentation and analysis.

The developed system can be further upgraded with various web modules designed to automate processes in particular sectors. An example of such an upgrade is a module for dynamic analysis of land areas crossed with the planned gas pipeline routes, which is intended to support decision making in the development sector. Its application is related to estimating investment costs when constructing a new gas pipeline, where it is necessary to define the optimal variant of the route geometry. A major impact on construction costs is the direction of the route through private and public land, and the land use. In order to estimate the land acquisition costs as close as possible and to optimize the route geometry with minimal construction costs, it would be useful to use this GIS module to accommodate and modify the route sections with an interactive display of the recapitulation of the land areas and the value of cadastral parcels in its buffer zone. The part of the module for report generation should provide table and graphical representation of the land areas recapitulation and values of the land and buildings covered by the buffer, comparing the various route versions.

In addition to expanding its functionality through new modules, this system can be further developed in terms of better use of analogue data, application of business intelligence and reporting functions. Namely, several spatial data sets that document infrastructure such as project and contract documentation including building drawings, architectural solutions, installation views, mechanical drawings, structural data, technical specifications, etc., will still be available only in the analogue format, which reduces the efficiency of their use in terms of access, manipulation, distribution and duplication. These data are of importance for further development of the infrastructure and are continuously updated for most of the services related to both maintenance and construction of gas facilities. By developing a digital archive information system (DA), it would be easy to handle this information through spatial search and further updating. The Web application with a database of archive documents provides metadata schema management, workflows and review and search functions in any text (full text), and metadata combined with spatial search on the map. The system uses the Qualified Dublin Core (QDC) schema, and enable the import and export of metadata as well as metadata with a spatial search component using the Minimum Bounding Rectangle (MBR).

By developing the BIS (Business Intelligence System) and reporting systems, the strategies and technologies used in the organization to analyze data and business information would be integrated with historical, current and planned views of business operations. Also, with a growing number of customers, there is a growing need for more efficient and cost-effective technologies for maintaining, improving and further building of the infrastructure. Building Information Modelling (BIM) is widely accepted in the construction industry and with its well-established methods and technologies

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it has enormous application potential for the gas transport industry (Costin, Adibfar, Hu, & Chen, 2018).

All this together leads to BCM (business continuity management) and the organizational structure for managing operations that can recognize how to prevent incidents. If they happen, this structure can systematize incident management steps to protect people, business, technology, information and company reputation (de Castro Alves & Manhães Gomes de Almeida, 2015). Understanding this and having access to systems and data, the organizational structure for operations management can have a realistic view of responses that can be applied in the event of a breakdown of critical activities of the structure and ensure management of any consequences in any scenario without unnecessary delays in the delivery of its products and services.

5. Conclusion

In order to use data efficiently in a business environment, it is necessary to have tools for transforming them into useful business information. In today's business environment, location intelligence represents a new information technology paradigm introducing a spatial component in the decision-making process. The goal of introducing location intelligence is to help organizations increase efficiency, profit, and revenue, as well as enable data to be used to make location intelligent decisions. In today's world of globalization, information technology is a key element of successful business operations. Managers need new solutions based on information technologies, especially those related to decision support. In order to reduce the risks associated with spatial characteristics and ensure more efficient risk management, the application of spatial decision support systems becomes necessary.

This paper describes the introduction of location intelligence through the implementation of the WebGIS solution for presenting and managing spatial data of the gas pipeline infrastructure. Such a solution enables the monitoring of environmental conditions related to reliable and safe natural gas transport. The solution helps plan and maintain the gas pipeline network, providing spatial dimensionality of business information and location conscious decision making on gas infrastructure development. The described system meets the current needs of the sectors in the organization because its functionality is adapted to a collaborative environment (multiple sectors and organizations), exchange of up-to-date data via web services, and the need for interoperable data editing with various GIS, CAD, BIM and other tools. However, its successful application in the future implies further upgrades, both with functional web modules and by introducing new components of the archival data management system (digital archive) and business analytics (business intelligence).

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