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Geographic Information System of the Gas Network in Pakistan

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Abstract

The truthfulness and understandability of information is dependent upon the way it is presented. It is admitted now that almost 85% of the data in human brain is related to geography and we continuously keep upgrading urban information in our brain consciously or unconsciously. This information, if updated frequently, affects most of the decisions made in our life. Maps are considered an easy and comprehensive source of transferring geographical information on paper. Such information is generic in nature and valid for everyone using maps. At times these maps are organized and annotated with symbols and interfaces to customize them for specific industries. In the industrial/corporate works geography is vital for decision-making but the decisions can't be taken without complete information including both geographical and attribute information, i.e., spatial features and features lay on geography to reach a logical conclusion.

In the field of gas distribution and transmission it is desired to create infrastructure maps of Pakistan which will underlay the engineering projects of corporations/establishments and providing infrastructure services especially in metropolitans. The incorporation of geographic information system (GIS) maps in existing gas pipelines became an inevitable necessity to integrate existing maps with coordinate based systems. GIS mapping of network based systems facilitates the following to decision makers: (1) Network analysis, (2) Simulation of new network extensions, and (3) Search, edit, modify operations on digital maps which are near to impossible on manual or cartographic maps. This paper presents the implementation of GIS for the country's gas network. The design is specific for the distribution and transmission of the gas network in Pakistan. In an extension to the study, intelligent analysis techniques will be included that can be applied to make GIS more analyzable.

Keywords: Geographic Information System (GIS), usability, Gas, Network, Graphical user interface (GUI).

Introduction

GIS stands for "*Geographic Information System*". It is one of the advanced technologies for information management. It differs from an information system since the information in GIS is visualized on geography instead of man-made interfaces. Formally, it is a computer system to capture, store, query, analyze, and display geographical data. The collection of spatial (data related to space/location) and attribute data about entities is termed as *data capturing* where data is captured through satellites, remote sensing, and global positioning system (GPS) as shown in Figure 1 (Shaheen, Shahbaz, Rehman, & Aurangzeb, 2010). It ranges from normal survey methods to complex radio frequency techniques. The data collected by these means are stored in a centralized Geographical Database Server (GDS).

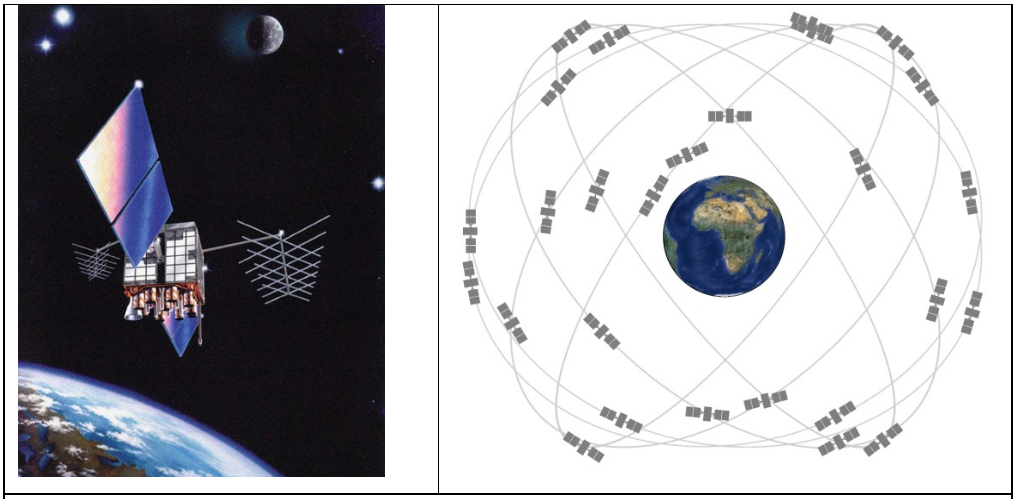

Figure 1: Global Positing System (Space Segment) – (copied from GPS.gov)

GIS enables users to put queries to a GDS through GUI. The results of queries are displayed back to its end users in an easy to understand format; e.g., to locate House # 22, Street.2, XY colony, the house in a colony or in broader sense to locate a building in the world, GIS assigns coordinates (latitude, longitude) to the building on digital map and facilitate user to give as input, coordinates or name of building in search window. The coordinates are usually annotated with a name by using the technique of Geocoding. Every location on earth is situated at a specific angle from equator. The location with respect to angle from equator is unique. These angles gave birth to imaginary horizontal (Latitude) and vertical lines (Longitude) across the globe. In GIS specific terms these are known as spatial data. After zooming to the location at desired latitude and longitude, the next step would be to have its complete details such as number of rooms in buildings, construction material used, date of construction, etc. Spatial data do not contain any information about these features. Such data is termed as attribute data or aspatial data. Aspatial data is incorporated in GIS through graphical user interfaces (GUI).

Pakistan was self-sufficient in energy specifically in two primary sources, i.e., oil and gas, a decade ago but the depletion point of oil and gas reserves in the country is fastly approaching. The country had huge natural gas reserves which are managed by two big companies of the country. The companies laid down transmission and distribution pipeline networks to deliver natural gas to the doorsteps. But there is lack of sustainability even in natural gas consumption and production (Shaheen, Shahbaz, Guergachi, & Rehman, 2011; Shaheen, Shahbaz, Rehman, & Guergachi 2011). One of the reasons for unsustainability is inappropriate management of data about oil and gas networks. The most ideal information system for management of laid pipeline network is a GIS which can play its role in multiple problem solving domains.

A gas network is complex in structure and imposes a number of constraints which affect efficient pipeline network management. Different structures of pipelines, diversity in network installations, network maintenance, and troubleshooting demand an information system that might be considered appropriate for the experts/ decision makers of pipeline network (Naqi & Siddiqui, 2006). To meet the requirements of pipeline network management, this paper proposes implementation of a GIS for gas network management and evaluates the appropriateness of the proposed application with the following evaluation parameters:

1. Efficient gas network management
2. Ease of use for the experts/ decision makers

The rest of the paper is organized in a systematic way. The next section presents a literature review of this topic. The Proposed Model section discusses the proposed method of GIS development and test case of the proposed method. The final section draws conclusion and propose future work.

Literature Review

Geo-databases are used to store geographic/ spatial and non-spatial data. These databases brought incredible change in mapping of network based information system as well as geo-spatial analysis. Geo-spatial data mapping is now a powerful tool for geo-analysis. In gas network management it is used to map, manipulate, analyze, and display the metrics of pipelines in an appropriate form. GIS in oil and gas exploration scenario is used to characterize and analyze reservoirs, characterize isotopic data, seismic and geological data, and Lineament data (Shaheen et al., 2010). GIS is also used to enhance tracer analysis which is done by incorporating GIS functions, such as statistical analysis of networks and cartographic mapping, in different software interfaces like conventional information system interface. The use of GIS in natural resource industry is discussed by various researchers; the details of these discussions are cited in Shaheen et al (2010). GIS is important not only in exploration but also in generating self-revenue by utilizing the services of petroleum exploration data management (Shah, 2006).

The diffusion of GIS is much lower in the industries of developing countries. An increase in the diffusion of GIS and other spatial technologies in these countries all in planning, development, and maintenance departments of the industries will optimally solve their problems. Robert LaBarbera in Fort Bend County US realized that GIS is not in public access as it is rarely articulated in newspaper and television. Internet, periodicals and conferences are the only sources of information of GIS (LaBarbera, 2007). The statement by LaBarbera is still valid for developing countries. Unfortunately all the three are not regularly used by planning departments in third world countries. Robert LaBarbera also identified that Fort Bend County individuals were not knowledgeable of new technologies and trends in GIS. The company was lacking in GIS personal resources and products and there was no GIS feedback from clientele. Dutch market research reflected that municipalities have low confidence in geographic data (Shaheen et al., 2010). This market research was made in the Netherlands when they were infant users of GIS. The growth level of GIS in various parts of the world (especially developing countries) is still very low. Onsrud & Masser (1993) argued that the initial rate of adoption of technology is slower until the volume of users increase.

Like other utilities, use of GIS is growing in the pipeline industry. ESRI (Environmental Systems Research Institute) provided GIS pipeline standards, the ArcGIS Pipeline Data Model (APDM) for the pipeline industry for assuring regulatory compliance and integrity management (ArcGIS Pipeline Data Model [APDM], 2013). The ArcGIS Pipeline Data Model is designed for storing information pertaining to features found in gathering and transmission pipelines, particularly gas and liquid systems. The APDM was expressly designed for implementation as an Environmental

Systems Research Institute’s (ESRI) geo-database for use with ESRI's ArcGIS and ArcSDE® products. A geodatabase is an object-relational construct for storing and managing geographic data as features within an industry-standard relational database management system (APDM, 2013). Key uses of a GIS include field data collection, environmental management, one-call management, land management, and right-of-way monitoring. GIS data and processes are available in the office, across the Internet, and in the field. APDM fits well on the current practices in pipeline industry in Pakistan. GIS can be considered as an option to replace two existing systems: (1) The pipeline network which is currently managed through paper maps and data sheets and (2) The pipeline network which is currently managed through information systems other than GIS.

GIS and remote sensing technology is not in a mature stage in Pakistan. A parcel-level system is not developed for individual cities due to which the mapping companies are facing many problems (Naqi & Siddiqui, 2006). The recent work in Pakistan is about starting the development of GIS for gas transmission and distribution network. But GIS is not only the name of cartographic mapping. It also adds network analysis features to conventional information system. The architecture of GIS is layered. It contains multiple layers of data plotted on a base map. The base map itself is considered as a layer in GIS. Two types of data are incorporated in GIS: Spatial data and Non-spatial data. Spatial data is plotted in form of map designed over remotely sensed satellite image (Korte, 2000)**.** The remotely sensed image analysis, commonly used in other domains, can also be used in pipeline network analysis. Different image interpretation techniques are provided in the literature for analysis of images. Remotely sensed data can be classified into spatial and non-spatial data, although the resulting analysis would require different mechanisms (Shaheen, Shahbaz, Rehman, & Guergachi., 2011). The West Virginia University used satellite imagery for hydrocarbon exploration in Virginia, collecting spectral reflectance data for vegetation discrimination. The rectified data was stored in a multi-temporal database so as to apply lineament analysis and monitor the effects of hydrocarbon presence on vegetation (Shaheen, Shahbaz, Rehman, & Guergachi, 2011).

This study cited a study in which the data indicating the location of hydrocarbon reservoirs was collected from exploratory wells. Data collection was relatively inexpensive and spatially complete in terms of prospecting hydrocarbon reserves in crystalline rocks. The data was combined with synchronous records of reflected seismic signals (Shaheen, Shahbaz, Rehman, & Guergachi, 2011). The use of analytical techniques on GIS or other information systems in the energy sector of Pakistan is rare (Shaheen, Shahbaz, Guergachi, & Rehman., 2011). Shaheen, Shahbaz, and Guergachi (2013) devised an intelligent analysis method of GIS by the name of context based spatio temporal association rule mining which is used to extract patterns present in satellite imagery on the basis of context variable.

In the light of the literature, this paper is about developing a holistic GIS for gas development network. The proposed GIS incorporates the capabilities of simple information system as well as geographic analysis capabilities to made its prospective broader.

Proposed Model

Components

As mentioned earlier, for proper network management of different network based companies like utilities companies, the mapping of GIS is essential and considered to be an important step towards dealing with energy losses. GIS maps the whole network of a company on a single grid which makes network analysis simpler hence providing a mechanism for controlling energy losses. The portfolio for such project can be different in different sets of circumstances. The development of GIS maps can either be for the conversion of manual paper maps to digital maps or for conversion of a conventional information system to a full-fledged geographic information system. In any of the gas network management companies of the world the model can be implemented with few changes for increasing its adaptability and to efficiently meet the needs of the staff. The development of the proposed GIS is explained in the following components;

1. Conversion of manual mapping system to GIS
2. Establishment of GIS center
3. Incorporation of analytical capabilities in GIS
4. Use of GIS in gas network management

In this paper we discuss the first component, i.e., "Conversion of manual mapping system to GIS". The rest of the components are not considered in the scope of this paper.

Conversion of manual mapping system to GIS

In this era of information technology the companies in developing countries are not very much familiar with the use of GIS. From the last five years a partial trend towards developing GIS maps in network based companies in Pakistan is fortunate. The business of gas network has two basic components: (1) Gas Transmission Network and (2) Gas Distribution Network. Gas transmission network deals with the pipeline from gas source to the city gate whereas the distribution network is appended at the end of transmission network, i.e., within the cities. Once the pipeline for transmission network or distribution network is laid, it is maintained, troubleshot, and managed through maps. There are certain companies which use manual mapping systems for network management. The maps are prepared on ammonia sheets which are quite poor in print quality, decays with the passage of time and slightly advanced than manual maps. These maps cause number of problems in daily operations to be performed by the companies. In order to convert such manual system to a full-fledges GIS, the steps to be undertaken are as under (Also given in Figure 2):

1. Procurement of satellite imagery for demarcated vicinity
2. Base map preparation
3. Collection of ammonia sheets (manual maps)
4. Scanning of ammonia sheets on large image scanner
5. Rectification of satellite image
6. Digitization of manual maps on digital maps
7. Preparation of graphical user interfaces
8. Ground verification of mapped facts/ data

Procurement of satellite imagery for demarcated vicinity

In order to convert a manual map system to a GIS, first of all, the area whose manual maps are already designed is identified and demarcated. Satellite image for the demarcated area is procured on per square kilometer basis. For example in Rawalpindi, the area where gas pipeline exists is 817 Sq. KM, hence the satellite image will be demarcated and sent to procurement department for purchase of image.

Base map preparation

Once the image is procured, necessary pre-processing is applied on the image to make it suitable for onward use in the GIS. All the noises, outliers, and missing parameters of the image are rectified to finally prepare a base map. The same base map serves as the first layer of the GIS.

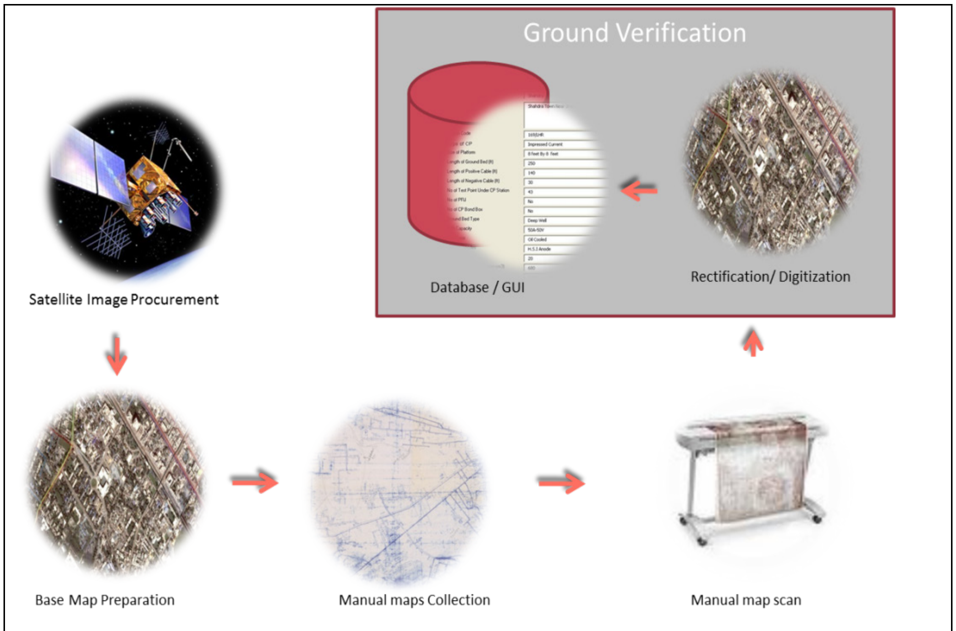

Figure 2: Step wise procedure for conversion of manual maps

Collection of ammonia sheets (manual maps)

As already discussed, a GIS is, in fact, the conversion of manual paper systems. It means that the existing gas network is currently mapped on ammonia sheets by conventional methods. The maps are collected from appropriate places/offices. There are certain offices in which third party vendors are involved in such activities – in that case the maps will be collected from the vendor. There are certain organizations which use cartographic mapping like AutoCAD to establish their network maps. It becomes much easier for GIS departments to map cartography on a GIS.

Scanning of ammonia sheets on large image scanner

After collecting ammonia sheets, the major task is to copy the manual pencil mapping from ammonia sheets to digital mapping through software. In the case of existing cartographic mapping, cartography is imported on to GIS instead of re-exercising the mapping practice, but if the maps are in the form of ammonia sheets then it is much more difficult and exposed to human err to digitize the maps manually. A proposal to undertake this activity is to scan all the ammonia sheets through large image scanner for onward processing.

Rectification of satellite image

The satellite image obtained from the vendor is not geocoded. Rectification is the process applied to convert raw satellite image to geo-coded image. The image after rectification is converted to latitude/longitude points. There are various projections available through which the process of rectification can be applied (Korte, 2000).

Digitization of manual maps on digital maps

This phase can only be achieved once the satellite image is rectified and ammonia sheets/manual maps are scanned through large image scanner. If the maps are cartographic, the overlaid cartography will simply be imported to lay on the satellite image. In case of ammonia sheets, the scanned sheets are supposed to be the base maps and the marked gas pipelines and other installations are digitized by using any cartographic mapping software.

Preparation of graphical user interfaces

At the completion of digitization phase, the skeleton of the GIS is complete. The next step is to record attribute data of marked network installations. The attribute data is recorded in two steps.

1. A relational database of all the network assets is established. This database will record the individual attributes of network assets in form of columns of tables. Each network asset is represented by one table.
2. The relational database created in the above step is oriented through the front-end. The front end of the database is called a graphical user interface (GUI). Hence each individual network asset is equipped with one GUI containing all the attributes of that asset.

Ground verification of mapped facts/data

Since the record of the network and its assets was previously recorded through ammonia print maps or cartographic maps, the facts may not have compliance with actual ground facts. It is necessary to verify each and every data point of the GIS with the actual network laid on the ground. This can be established in two steps.

1. The coordinates (Lat/Lon) on geocoded satellite image is verified with the actual GPS points taken from the ground.
2. The attribute data stored in the database and manipulated through GUIs is verified by ground inspection with state of the art devices.

Intelligent Analysis

The GIS model proposed above will convert the existing manual/ cartographic mapping system to an information system mapped on geography. This mapping will facilitate user with (1) basic functions of an information system, (2) Geographic mapping, (3) Network analysis. The retrieval, update, and deletion process has now become much simpler. But since a GIS is full-fledged information system mapped on geography, it is supposed to be equipped with analytical capabilities so as to support a decision and policy maker. The term "analysis" has different meaning in different contexts. In gas network analysis, the analysis is mostly depends upon the geographic reference as well as attribute values. The activities related to gas network analysis which we have included in our GIS model are:

1. UFG Analysis
2. Emergency Management
3. Integration with existing applications
4. Security management

UFG analysis

Unaccounted for gas (UFG) is one of the greatest concerns in a pipeline industry. In order to make GIS more capable for analytical tasks, a UFG analysis module is added to the proposed model. UFG is mainly caused because of two reasons: Leak in network and Gas theft. In order to avoid leaks and investigate theft cases, a leak rectification module is added to the GIS model. A leak rectification module takes a selected network portion as input and predicts leaks on the basis of outliers in incoming and outgoing pressure.

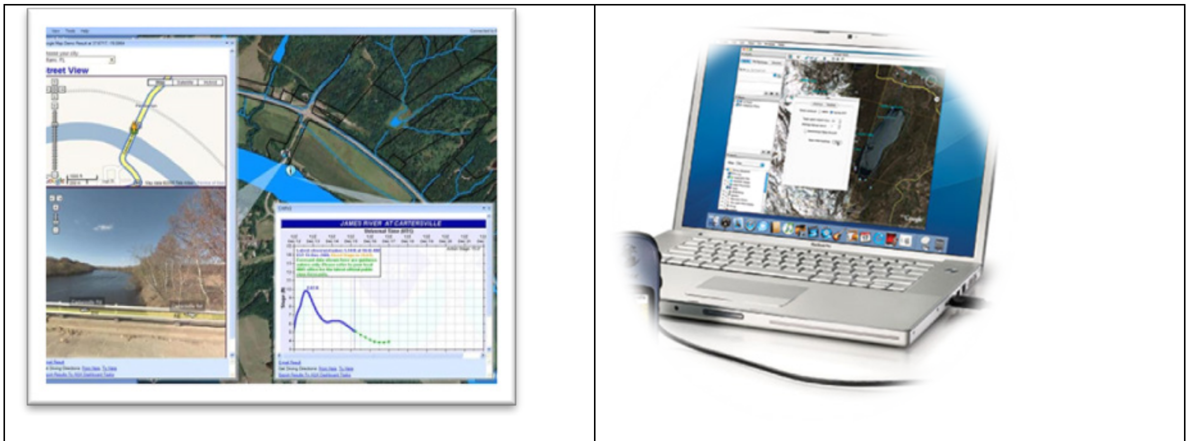

Figure 3: UFG Analysis on Desktop GIS

Emergency management

The occurrence of an emergency in the pipeline network is not an unusual routine. Since gas with much higher pressure is there in the pipe hence the decision makers should always remain ready to mitigate an emergency. The proposed model provides an appropriate and efficient planning capability to deal with an emergency situation like a pipe burst. The method of responding to emergency is GPS based. In case of an emergency a service man would need to go to the point of emergency with GPS to take the coordinates of the pipe where emergency took place. The GPS will then be plugged with the GIS to access the point of emergency on the map. An automated emergency analysis module is provided to prepare an optimal plan for dealing with emergency on desktops.

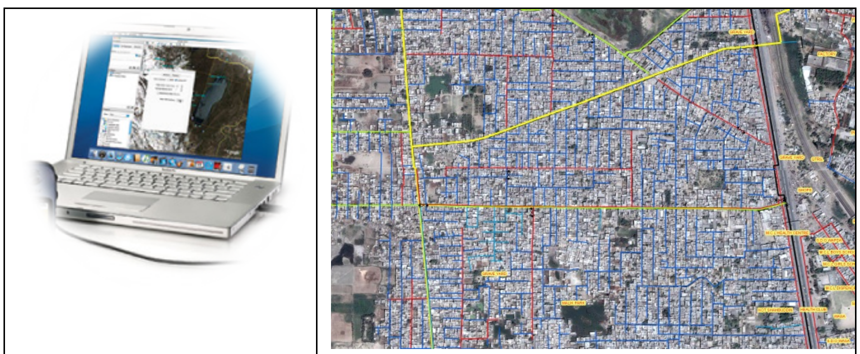

Figure 4: Searching point of emergency and dealing with emergency through GIS

Integration with existing applications

Every gas company uses certain engineering software for various analyses. This software is well understood by the engineers or other personnel of the company. The proposed model does have the capability of integrating this software with the proposed GIS. By establishing such an integration the system will be more equipped and will facilitate other systems to take GIS data as input.

Security/ schema management

Every user of the system has different requirements in perspective of GIS use. In the proposed model, user schema management is introduced to provide the users with specific rights with respect to their requirements. For example, the sales department of a gas company does not need to access the flow analysis capability of the system. Hence, the users from the sales department are provided with the rights to check and use sales metrics of the system. All other functionalities of the system are blocked for such users.

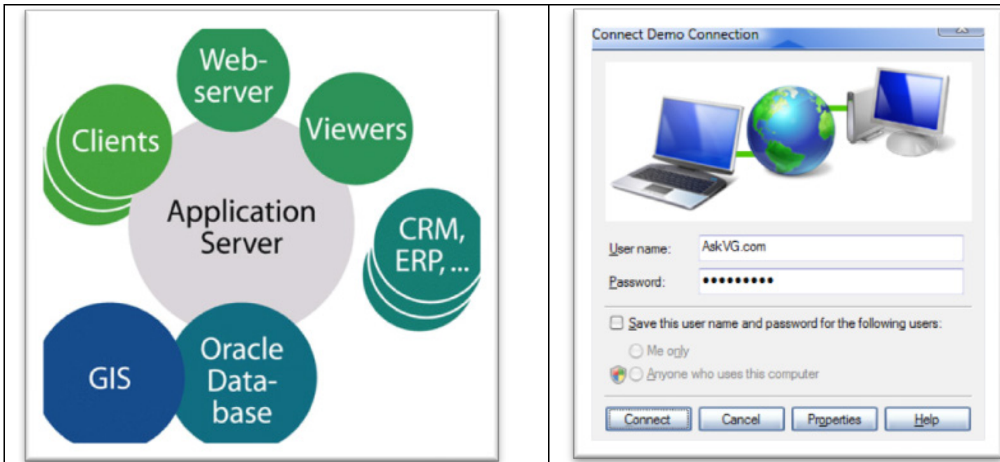

Figure 5: User schemas and its integration in applications

Conclusion & Future Work

We have presented an overview of the reasons for the non-diffusion of GIS in pipeline industry of developing countries. The reasons concluded to be the lack of adaptability and unawareness. We proposed design of GIS that is unique in the following two aspects:

1. Specificity of GIS for gas network
2. Incorporation of required analytical capabilities

   The work was divided to be completed in four phases out of which only one phase, i.e., Conversion of manual cartographic mapping or ammonia print maps to GIS, is considered only in this paper. The work will be extended to include the rest of three activities, i.e., Establishment of GIS center, Incorporation of analytical capabilities in GIS, and use of GIS in gas network management. These are not discussed in the paper. The conventional design of GIS is enhanced to include intelligent analysis capability. The most prominent issues of pipeline industry which need thorough and complex analysis are added as modules in the system. The system is unique than conventional information system for inclusion of geographic data manipulation, retrieval and analysis. Following aspects of the converted system reflected improvements.

   1. Data retrieval, query and storage
   2. Appropriate representation of data
   3. Ease of use
   4. Similarity with the system well practiced
   5. Analysis capabilities
   6. Efficiency in terms of speed and capacity
   7. Information diffusion
   8. Information availability

The work will be extended to include the following capabilities in future

i. Establishment of GIS center
ii. Incorporation of complex and generic analytical capabilities in GIS
iii. Appropriate uses of GIS in network management

Standardization of symbology in different layers of GIS can also be incorporated to enhance usability and scope of the information system. Automated method of data collection and elicitation would also be good enhancement to the current system.

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Glossary of Terms

(i). **Geo-spatial data**: Geological data can be of two types. (1). That is related to space (2). That describes attributes. Geo-spatial data is the geological data related to space (coordinates, x point etc).

(ii). **Geo-databases**: The databases that store data related to earth.

(iii). **Reservoirs**: The containers that contain oil, gas or other natural resources.

(iv). **Isotopic data**: Radioactive form of a particular element gives isotopic data.

(v). **Seismic data**: Oil and natural gas companies use seismic data as their principal source of information to locate oil and natural gas deposits, both to aid in exploration for new deposits and to manage or enhance production from known reservoirs. To gather seismic data, an energy source is used to send sound waves into the subsurface strata. These waves are reflected back to the surface by underground formations, where they are detected by geophones which digitize and record the reflected waves. Computers are then used to process the raw data to develop an image of underground formations (source: http://www.ultrapetroleum.com/About-Us/Glossary-of-Terms-14.html)

(vi). **Geological data**: The data which come from research on solid earth materials.

(vii). **Lineament**: Lineament is a linear feature on surface of earth such as fault.

(viii). **Tracer analysis**: The analysis of compound's concentration.

(ix). **Spatial technologies**: The technologies that are used for analysis, use and manipulation of spatial data.

(x). **Remote Sensing**: A method of data collection in which the data is collected through spaceborne instruments e.g. satellites or aerial imagery.

(xi). **Parcel-level system**: Demarcation of various buildings, streets, housing on satellite image in vector form make parcels.

(xii). **Cartographic mapping**: Study and practice of making maps is called cartography. The most popular software for cartographic mapping is AutoCAD.

(xiii). **Transmission Network**: The pipeline for gas through which the gas travels from source (gas well) to gates of cities.

(xiv). **Distribution Network**: The pipeline laid within the cities to supply gas from city gates to doorsteps.

(xv). **Rectification**: The process of converting satellite image on true coordinate system i.e. latitude and longitude is called rectification.

Biographies

Dr. Muhammad Shaheen, Ph.D., Associate Professor (Computer Science) FAST – NUCES Pakistan was born in Haripur, Pakistan in 1980. He received Bachelors and Masters degree in computer science from University of Peshawar in 2000 and 2002 respectively, and the M.Phil degree from Foundation University Islamabad in 2007. He got his Ph.D degree in computer science from University of Engineering & Technology Lahore Pakistan in 2011. He got gold medals in recognition of his performance in M.Sc and M.Phil. In 2003, he joined Sidat Hyder Morshed Associates Islamabad as computer programmer and in 2004 became Sr. computer programmer. He joined Sui Northern Gas Pipelines Ltd., in the year 2006 where he served as GIS Manager in corporate planning & development department of the company till 2011. Since then he has been serving as Associate Professor (Computer Science) at FAST – NUCES Peshawar. His current research interests include data mining, remote sensing, software metrics, databases, artificial intelligence, industrial problem solving and operations research. Dr. Shaheen has a broader experience of research and development in various domains of computer science. He worked on different projects in the country. He published number of research papers in journals and conferences of international repute. He has also been serving in board of reviewers of different international research journals and conferences. He is a member of ACM, SEI, WCE National Academy of science and Informing Science Institute.

Mr. **Zia ur Rehman** was born in Haripur, Pakistan in 1979. He has been serving as "IT Manager" in Pak International Consultants & IT Solution Providers, Haripur, KPK Pakistan. Mr. Zia started his career by joining a non-government organization "Tanawal Youth Wing" as Computer Operator. He then joined the company in which he is currently working as IT Assistant in 2010. He has been promoted to the post of IT Manager in the recent past. His field of work is office automation, GIS operations, imaging and basic editing operations. He is currently supervising the IT section of the said company. He is a member of Informing Science Institute and attended inSITE conference of the same organization held in Varna, Bulgaria in 2008.