



**ADDIS ABABA UNIVERSITY
SCHOOL OF GRADUATE STUDIES
COLLEGE OF NATURAL SCIENCES
DEPARTMENT OF COMPUTER SCIENCE**

**GIS Based Multi-user Underground Utility Map Co-editing and
Authentication for the Case of Addis Ababa**

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CO-EDITING AND AUTHENTICATION**

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Dedication

To my grandmother: You have been working so hard to raise me and my brother. You are the hero in my life for the things you did to me. May God bless you and give you a long life and good health.

To my grandfather: I appreciate your efforts and struggles to show me the route that brings me to the today's fruit. May God bless you and put your soul in heaven,

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Last but not the least, my family for their love, material and moral support in my course and research endeavors and the one above all of us, the omnipresent God, for answering my prayers for giving me the strength to plod on despite my constitution wanting to give up and throw in the towel, thank you so much Dear Lord.

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Acronyms

AA	Addis Ababa
AAWSA	Addis Ababa Water and Sewerage Authority
AM	Automated mapping
AOI	Area of Interest
API	Application Program Interface
ArcSDE	ArcGIS Spatial Database Engine
APWA	American Public Works Association
CAD	Computer Aid Design
CS	Coordinate System
EEPC	Ethiopian Electric Power Corporation
ERA	Ethiopian Road Authority
FM	Facility Management
GCS	Geometric Coordinate System
GIS	Geographic Information System
GPR	Ground Penetrating Radar
MUUMCA	Multi-user Underground Utility Map Co-editing and Authentication.
PCS	Projected Coordinate System
PL	Procedural Language
RE	Residual Error
RMSE	Root Mean Square Error
SDK	Software Development Kit
SLD	Styled Layer Descriptor
SQL	Structured Query Language
WMS	Web Map Server

Abstract

Public utility authorities are facing significant challenges in developing cost effective business process for managing underground infrastructures and assets. People working in the utility industry need a better understanding of the context of change, what it means, and how they can manage their present and their future utility resources. Geospatial information of utilities changes continually and geospatial datasets become outdated and unsuitable for decision support due to inadequate data quality which leads to high maintenance cost. Integrating different underground utilities spatial data together in GIS-centric utility management using geodatabase and creating a workflow to edit underground utility map of one service provider utility spatial data without affecting other utility service provider in automated and systematic way is vital.

This thesis presents a model for the development of Underground Utility Map Co-editing and Authentication system for public utility service providers using versioning approach. The system makes use of underground utilities base map information, and ground control points in order to prepare the utility spatial data as input for further tasks. The spatial preprocessing component is responsible to transform coordinates, convert utility map format and topological error correction in order to have a good quality spatial data. The system supports a mechanism for versioned geospatial data editing and more importantly support support commits that could span many days.

To evaluate the quality of underground utility map layers, data from utility services (ethio telecom, Water & Sewerage Authority, Ethiopian Electric Power Corporation and Road Authority) of Addis Ababa is collected and preprocessed. The coordinate transformation and map accuracy is evaluated using Root Mean Square Error metric and we have got an average map accuracy of up to 3 meters. Finally, the proposed system is evaluated by eight respondents from all service providers and we got overall system performance of 86.6%. From this result, it is possible to conclude that, the proposed work and its implementation is usable to provide utility services, to co-edit maps and authenticate utility maintenance services.

Keywords: *Versioned editing, utility mapping, multi-authority editing, long transaction, Utility network service.*

Chapter One: Introduction

1.1 Overview

A Geographic Information System(GIS) is created by combining hardware, software and people together that are capable of capturing, storing, analyzing, managing, and presenting data having spatial components (geographically referenced data) [1]. This technology has enabled users and non users alike to make decisions based on information not easily understood by text only data formats [3].

GIS has played an integral role in the expansion and maintenance of the public utilities Infrastructure management and development plans. The term „public utility“ encompasses a wide variety of industries including, among others, airlines, telecommunications, oil, natural gas, electricity, trucking, cable television and railroads [2]. These industries share a common network structure, in that they have an extensive distribution system of lines, pipes, or routes often with strong physical linkages between component parts. GIS does this by keeping accurate records of utilities, with the development of the cities environmental and natural resources, implementation of emergency management processes and assuring the quality of service provided.

Beneath the surface of cities worldwide, an extensive and complex network of pipes and cables providing the essential utility services that underpin modern civilized life [55]. With the ageing of this buried infrastructure and growing demand for new underground utilities due to the expansion of the population and the development of new technologies, it is vitally important both to locate the existing underground infrastructure and manage utilities spatial information using GIS.

Ethiopia has four core public utilities and transportation service providers“ ethio telecom, Ethiopian Electric Power Corporation (EEPC), Ethiopian Water and Sewerage Authority (EWSA) and Ethiopian Road Authority (ERA). These four utility service providers help the community of the nation by providing telecommunication, electricity, water and sewerage supplies, and transportation services. In order to provide the above services, service providers

installed their infrastructure like water pipeline, telecommunication line and electricity line above or below the ground.

The City of Addis Ababa has utilities that installed underground; with the goal of providing the highest quality service possible using the industry's most advanced technology. Many of these utilities are cut down usually by the side of a road whose construction is associated to the ERA.

However, to provide the above services to the residents of the city, each utility service provider should protect its own infrastructure from natural and manmade damages. Although, it is very difficult to protect service providers' infrastructure from natural disaster like fire, flood, earthquake etc; we can protect utilities from manmade damages. Due to lack of systematic communication among service providers on the existing infrastructure, it is very common to see that, technicians don't know where the underground infrastructures are located which leads one service provider damages utilities of other service provider. For this reason, damages on underground infrastructure highly affect the service providers not to provide their services to the public properly and that costs much to maintain those underground infrastructures of each service provider.

1.2 Motivation of the Study

This work will use GIS technology in application areas of public utility management. The advent in GIS technology which is regarded as the next wave in the evolution of utility management, the growth of tools for maintaining infrastructure spatial information, and the rising use of technologies like ArcSDE, ArcGIS for desktop and server are also among the key motivations for this work.

The main focus of this work is the capital city of Ethiopia, Addis Ababa on providing telecommunication, electricity and water utility services and which install their infrastructures underground. Currently it is a common event to see that at the time of installing new underground infrastructure one's utility infrastructure is damaged by another utility service provider. This damage of infrastructure has many impacts: the resident of the city may not get the service properly, it incurs too much cost to maintain the damaged infrastructure and this may

also have a social and moral damage both on service provider's reputation and on the residents of the city. Providing a solution to the city's problem is the key motivation of this work.

1.3 Statement of the Problem

This is a time of major change in the utility industry. Utilities throughout the world are facing unprecedented change due to privatization, deregulation, urban development and the introduction of advanced technology [56]. A systematic approach which reduces damages on infrastructure of utility service provider is needed. Currently, GIS-based utility data management systems and solutions help the utility providers to leverage operational efficiency, provide superior services and manage cost effectively.

Nowadays, underground infrastructures of service providers expand continuously and unless geospatial information of utilities is also updated accordingly, it will be unsuitable for decision making.

Water, telecommunication and electricity utility service provider authorities in Ethiopia to provide their services to the public, they buried their utility below the earth surface. Due to lack of GIS based systematic communication among service providers and transportation authority while installing their infrastructures, one service provider damages infrastructure of the other. This causes the service providers to disrupt their services to the society and not to meet their service goal and incur high maintenance cost.

Based on the information gathered on these utility service providers, there is no work to handle this problem so far. It is a high time that a system is in place to solve such a problem.

1.4 Objective

General Objective

The main objective of this thesis is to design a GIS based multi-user georeferenced underground utility map co-editing and authentication.

Specific Objectives

In order to achieve the above goals, the specific objectives are:

- Explore the existing map database tools and technologies.
- Investigate the current situation in underground infrastructure management of utility service provider in Ethiopia and identify the problems.
- Design architecture for centralized GIS based location authentication and geospatial editing for utility service providers.
- Develop a prototype to demonstrate the proposed work.
- Test and evaluate the system performance.

1.5 Scope and Limitation

The main scope of this work is to design a Multi-user underground utility map co-editing and authentication using versioning approach, develop a system based on a model, test and evaluate the underground utility map accuracy. This study does not include locating underground infrastructure leakage and not works for service providers which doesn't have utility base map.

1.6 Methodology

Literature Review

Detail review and assessment will be made on different related works to know the actual problem with current GIS based infrastructure location authorization strategies and a new approach that can efficiently solve the problems will be derived.

Data Collection

Training set utilities infrastructure base map of data will be collected from at least three utility service providers to identify the problems and the requirements to design a new geospatial database which can store and manage different infrastructure spatial and non-spatial information.

Development of a Prototype

A prototype which can authorize service provider before installing their infrastructure will be developed. Various tools are used for the development: ArcSDE and Oracle XE 11g for utility

map database design, ArcGIS desktop for spatial data preprocessing, to implement the code, java programming language and Arcsde API'S; WMS and geoserver are used as a web server and openLayers are used to publish utilities on the web.

Experimental Evaluation

Proper testing will be made and the newly proposed solution will be evaluated in terms of its goals and contributions in comparison to what is already there.

1.7 Application of Results

A multi-user underground utility map co-editing and authentication system can be used to:

- Manage underground infrastructure map information easily.
- Identify the location of buried infrastructure easily.
- Determine the distribution of the infrastructure to the society.
- Control and supervise unauthorized excavation or lay down of underground infrastructures easily.
- Provide up to date utility spatial information to service providers.
- Co-edit underground utility map.

The general application result of the proposed work will enable to access asset data quickly and efficiently, saving both time and money for all service providers, helping to improve on-site safety and protecting underground assets from accidental damage.

1.8 Organization of the Thesis

The rest of the thesis is organized as follows. Chapter 2 discusses literature review on different issues in underground utility monitoring. In this Chapter, geographic data modeling and its constituents, types of geodatabase and their architectures, types of spatial data representation model are discussed.

Chapter 3 is devoted to discuss related works done on GIS based underground utility monitoring system developed in different countries. Chapter 4 specifies the overview and architecture of a multi-user underground utility map co-editing and authentication (MUUMCA). Description of its basic components and geodatabase spatial data editing workflow through each utility service

provider underground infrastructure is presented. Chapter 5 discusses the implementation, the evaluation of utility map layers using metrics, tools and techniques to develop MUUMCA system and discussion of the result is presented. Chapter 6 concludes the thesis by outlining the benefits obtained from the research work and limitations of the system. It also shows some research directions and recommendations that can be accomplished in developing a GIS based underground utility map co-editing and authentication system.

Chapter Two: Literature Review

This Chapter presents a review of literatures conducted in order to understand the problem associated with the area of the objectives of this thesis and also to identify appropriate direction. Overview of GIS application on different public utilities in different countries, and an extensive review is made on areas of underground utility management, spatial data modeling approaches, spatial data editing techniques and GIS and geodatabase technologies that support the success of underground utility monitoring.

2.1 Overview of GIS Technology on Public Utility Monitoring

GIS plays a great role on monitoring basic underground infrastructures in different countries. Some of the application areas are water distribution and resources, electric and gas, telecommunication, transportation etc.

2.1.1 Application of GIS in Water Distribution and Resources

GIS had been proven to be an effective and powerful tool in the water distribution industry. According to the American Water Works Association (AWWA), as of 2002, 90% of water agencies were at least partially using GIS to assist in applications [4]. An application is an applied use of technology which bridges the gap between pure science and applied use. An example for use in the water utility is a Computerized Maintenance Management Systems (CMMS). It can have many functions. For example, it can provide maintenance cost and history along with providing asset inspection data and asset condition assessment. Integrating with a GIS can improve the capabilities of a CMMS by supporting spatial analysis and locating geographically dispersed facilities in the water system. A GIS is a special type of information system in which the database of spatially distributed features and procedures collect, store, retrieve, analyze, and display geographic data. GIS relates database records and associated attribute data to a physical location, creating a "smart map" [5]. A GIS is also a means of effectively analyzing large amounts of spatially related data. Making informed infrastructure maintenance decisions requires large amounts of diverse information on a continuing basis. GIS

integrates all kinds of information from disparate sources into one manageable system so better and informed decisions can be based on all relevant factors. With the integration of information from a variety of sources, it is possible to determine important geospatial relationships and factors on which utility maintenance would be based. For example, water main failure could be caused not only by age, but also by pipe material, surrounding soil, water pressure, and street traffic. By analyzing these factors and other related factors, it would be possible to determine which assets are the "hot spot" areas and constitute a priority for maintenance activities. According to Shamsi [4], the use of GIS technology can be an ideal solution for the effective management of water industry infrastructure because it offers the power of both geography and information systems. The key element of information used by a water utility is its location to geographic features and objects. According to some estimates, more than 80% of all information used by water utilities is georeferenced making GIS technology especially applicable as a management tool. Spatial location is typically a major common aspect of all the data at water, electric and telecom utility. A GIS can locate the exact position of a utilities infrastructure such as valves, hydrants, meters, pumps, and fiber optics covers displaying them on a computerized map. It can also store important data about each utility, including manufacturer, year of installation, repair history, size volume, water quality data or almost any other type of information. Efficient management must include location information so good decisions can be made relative to the surrounding area and affected utilities. With the use of GIS in the area of utility management, it is possible to visualize and understand the geographical context of an asset and improve the efficiency of underground utility management.

2.1.2 Application of GIS in Electric and Gas

Beirut is analyzing its power circuits to minimize losses and to improve voltage levels. GIS is modeling scenarios of device placement for optimal electrical benefit. Public Service of New Mexico is using GIS to manage the construction, operation, and maintenance of 2,500 miles of power transmission. A prime concern is preventing environmentally damaging activities [7].

2.1.3 Application of GIS in Telecommunications

In Colombia, the fiber-optic trunk network is being captured in a GIS database with a representation of each of the network's element features [7]. In Indonesia, GIS is employed to

manage radio telephony by studying radio station placement, the demographics of a customer area, and the maintenance of equipment. A telecommunications consulting firm is using data on land use and land cover to predict signal attenuation for wireless communication systems.

2.1.4 Application of GIS in Transportation

In Korea, a GIS monitors real-time traffic conditions to mitigate traffic bottlenecks on freeways. The State of Georgia applies GIS technology to manage roadway pavement [7]. A study was made of road segment ratings based on load cracking.

2.2 Geographic Data Model

The heart of any GIS is its data model [6]. A data model is an abstract representation of some real-world situation used to organize data in a database. Data models typically consist of three major components. The first is a set of data objects or entity types that form the basic building blocks for the database. The second component is a set of general integrity rules which constrain the occurrences of entities to those which can legally appear in the database. The final component includes operators that can be applied to entities in the database [10].

Data modeling involves three different levels of abstraction: conceptual, logical and physical levels. Conceptual data models describe the service provider of data at a high level of abstraction, without taking implementation aspects into account. A logical data model translates the conceptual model into a system-specific data scheme, while low-level physical data models provide the details of physical implementation (file service provider and indexes) on a given logical data model [11].

The most widely used logical data model that supports the node-arc representation of networks is the georelational model. This model separates spatial and attribute data into different data models. A logical spatial data model (the vector data model) that encodes nodes and arcs maintains the geometry and associated topological information, while the associated attribute information is held in relational database management (RDBMS) tables. Unique identifiers associated with each spatial entity (node, arc) provide links to records in the relational model and its data on the entity's attributes. This hybrid data management strategy was developed to take advantage of a relational database management system to store and manipulate attribute

information [6]. But this solution does not allow the relationships between a spatial object and its attributes have their own attributes [12]. Though the solution is neither elegant nor robust, it is effective and the georelational model is widely present in GIS software [10].

ArcInfo 8 introduces a new object-oriented data model the geodatabase data model that is capable of representing natural behaviors and relationships of features [6]. To understand the impact of this new model, it is instructive to review three generations of geographic data models.

2.2.1 CAD Data Model

The very first computerized mapping systems drew vector maps with lines displayed on cathode ray tubes and raster maps using overprinted characters on line printers. From this genesis, the 1960s and 1970s saw the refinement of graphics hardware and mapping software that could render maps with reasonable cartographic fidelity. In this era, maps were usually created with general purpose CAD (computer-aided design) software. The CAD data model stored geographic data in binary file formats with representations for points, lines, and areas. Scant information about attributes was kept in these files; map layers and annotation labels were the primary representation of attributes [6].

2.2.2 Coverage Data Model

In 1981, Environmental Systems Research Institute (ESRI) introduced its first commercial GIS software, ArcInfo, which implemented a second generation geographic data model; the coverage data model also known as the georelational data model. This model has two key facets: the first facet, spatial data is combined with attribute data. The spatial data is stored in indexed binary files, which are optimized for display and access. The attribute data is stored in tables with a number of rows equal to the number of features in the binary tables and joined by a common identifier. The second facet, topological relationships between vector features can be stored. This means that the spatial data record for a line contains information, about which nodes delimit that line, and by inference, which lines are connected; it also contains information about which polygons are on its right and left sides [6].

The major advance of the coverage data model was the user's ability to customize feature tables; not only could fields be added, but database relates could be set up to external database tables.

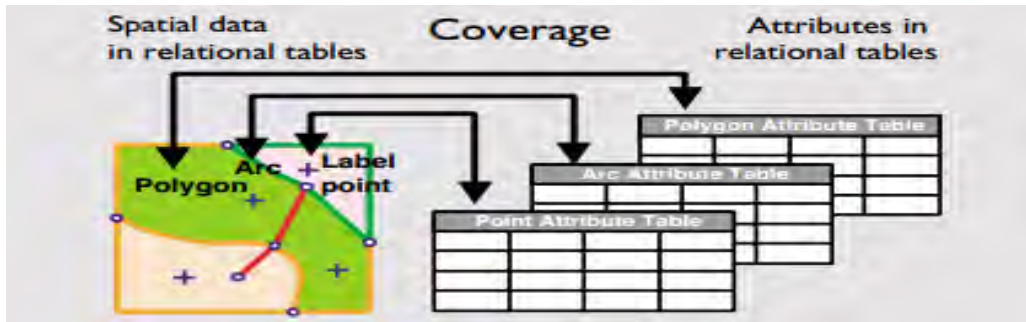


Figure 2. 1: Coverage data model

Because of the performance limitations of computer hardware and database software of the time, it was not practical to store spatial data directly in a relational database. Rather, the coverage data model combined spatial data in indexed binary files with attribute data in tables as we shown in Figure 2.1. Despite this compromise of partitioning spatial and attribute data, the coverage data model has become the dominant data model in GIS. The coverage data model made high performance GIS possible and stored topology facilitated improved geographic analysis and more accurate data entry.

Limitations of the coverage data model

However, the coverage data model has a serious shortcoming; features are aggregated into homogeneous collections of points, lines, and polygons with generic behavior. The behavior of a line representing a road is identical to the behavior of a line representing a stream. The generic behavior supported by the coverage data model enforces the topological integrity of a dataset. For example, if you add a line across a polygon, it is automatically split into two polygons. But it is desirable to also support the special behaviors of streams, roads, and other real-world objects. An example is that streams flow downhill and when two streams merge into one, the flow of the merged stream is the addition of the two upstream flows. Another example is that when two roads cross, a traffic intersection should be at their junction unless there is an overpass or underpass.

2.2.3 Geodatabase Data Model

ArcInfo 8 introduces a new object-oriented data model called the geodatabase data model [6]. The defining purpose of this new data model is to make features in GIS datasets smarter by endowing them with natural behaviors, and to allow any sort of relationship to be defined among

features. The geodatabase data model brings a physical data model closer to its logical data model. The data objects in a geodatabase are mostly the same objects you would define in a logical data model, such as owners, buildings, parcels, and roads. Further, the geodatabase data model lets you implement the majority of custom behaviors without writing any code. Most behaviors are implemented through domains, validation rules, and other functions of the framework provided in ArcInfo.

Benefits of Geodatabase Data Model

The common thread throughout these scenarios is that it is very useful to apply object-oriented data modeling to features. Object-oriented data modeling lets you characterize features more naturally by letting you define your own types of objects, by defining topological, spatial, and general relationships, and by capturing how these objects interact with other objects. Some of the benefits of the geodatabase data model are:

- A uniform repository of geographic data. All of your geographic data can be stored and centrally managed in one database.
- Data entry and editing is more accurate.
- Users can work with more intuitive data objects.
- Better maps can be made.
- Shapes of features are better defined.
- Many users can edit geographic data simultaneously.
- A principal advantage of the geodatabase data model is that it includes a framework to make it as easy as possible to create intelligent features that mimic the interactions and behaviors of real-world objects.

2.3 Data Representation Model

Geographic data may come in vector form, raster form, or in both forms. Spatial objects are said to be in vector form if they are represented by one of the basic discrete entities such as points, lines, and areas (polygons) which are spatially referenced by a Cartesian coordinate system [8, 9]. The same spatial object entities can be represented in raster form if they can be decomposed into pixels. Each pixel is referenced by row and column positions. Representing spatial objects as raster or vector has its advantages and disadvantages. Vector representation easily offers better

accuracy than raster representation because entities are represented by exact coordinates in space and do not have their locations generalized to a pixel. Thus, raster gives more approximate locations for the represented entities. Further comparisons of these two representations such as based on handling topology is explicitly described in the vector form and therefore this is good for tasks such as network analysis. However, geometric data processing such as coordinate transformation is difficult (requiring re-sampling) in raster but easy to perform in vector form.

2.3.1 Variety of Vector Models

a. Topological Model

The idea behind the topology model is that all geometric objects and digital map data can be represented by nodes and links [6]. The objects' attributes and relationships can be described by storing nodes and links in three tables: a polygon table, a node topology table, a link topology table, and also an additional table that gives the objects' geographical coordinates and is stored separately from the attribute data files.

b. Network Model

A network model is described as a graph named connectivity graph that maintains the connectivity information about spatial features with line or point geometry [6]. The basic elements of a network model are edges, junctions and turns. Features with point geometry are represented with junction elements inside the graph, while lines are represented as one or more edge elements between pairs of junction elements. Network elements are used only to describe the connectivity information for the spatial features they are representing; they do not carry any geometrical properties.

Utility Network Model

A network is referred to as a pure network if only its topology and connectivity are considered. If a network is characterized by its topology and flow characteristics (such as capacity constraints, path choice and link cost functions) it is referred to as a flow network. A utility network is a flow network representing different underground utilities like water, electric, telecommunication and gas utilities [6].

Transportation Network Model

A transportation network is a flow network representing the movement of people, vehicles or goods [13].

Shapefile

A shapefile is a digital vector storage format for storing geometric location and associated attribute information. The shapefile format was introduced with ArcView GIS version 2 in the beginning of the 1990s. It is now possible to read and write shapefiles using a variety of free and non-free programs. Shapefiles are simple because they store primitive geometrical data types of points, lines, and polygons. These primitives are of limited use without any attributes to specify what they represent. Therefore, a table of records will store properties/attributes for each primitive shape in the shapefile. Shapes (points/lines/polygons) together with data attributes can create infinitely many representations about geographical data. They store geometry & attribute information for geographic features in a data set. Geometry for a feature is stored as a *shape* comprising a set of vector coordinates linked to their attributes; Shapefiles usually comprise 3 separate & distinct types of files: main files, index files, and database tables.

- Main file (e.g., counties.shp) is a direct access, variable record length file that contains the shape as a list of vertices.
- Index file (e.g., counties.shx) contains character length & offset (spaces) information for locating the values
- Database table (e.g., utilities.dbf) that contains the attributes that describe the shapes.

2.4 Spatial Data Analysis

This deals with the methods of acquiring information that is not only directly stored in a spatial database, but also information that can be newly generated based on the existing data using certain methods [12]. Some of spatial data analysis functionalities are:

a. Spatial Relationship

Spatial relationship specifies how some object is located in space in relation to some reference object. In spatial database and geospatial topology the spatial relations are used for spatial

analysis and constraint specifications. Commonly used types of spatial relations are: topological, directional and distance relations [12].

b. Topological Relations

Topological relationships support map reading and allow important spatial decisions disjoint, containment, overlapping, intersects, touches, crosses, and equals [14].

c. Directional Relations

Directional relations can again be differentiated into external directional relations and internal directional relations. An internal directional relation specifies where an object is located inside the reference object while an external relations specifies where the object is located outside of the reference objects north of, south of, etc.[15].

d. Distance Relations

Distance relations specify how far an object is away from the reference object [16]. Example: nearby; in the vicinity; far away etc.

e. Network Connectivity Rules

Network connectivity rules constrain the type of network features that may be connected to one another and the number of features of any particular type that can be connected to features of another type. By establishing these rules, you can maintain the integrity of the network connectivity in the database.

2.5 Coordinate Transformation

Coordinate transformation is a process of converting an object from one coordinate system to another [17]. In geometry, a coordinate system is a system which uses one or more numbers, or coordinates, to uniquely determine the position of a point or other geometric element on a manifold such as Euclidean space. The order of the coordinates is significant and they are sometimes identified by their position in an ordered tuple and sometimes by a letter, as in "the x coordinate". The coordinates are taken to be real numbers in elementary mathematics, but may be complex numbers or elements of a more abstract system such as a commutative ring. The use

of a coordinate system allows problems in geometry to be translated into problems about numbers and vice versa; this is the basis of analytic geometry.

Types of coordinate systems

The following are two common types of coordinate systems used in a geographic information system (GIS):

- A global or spherical coordinate system such as latitude-longitude. These are often referred to as geographic coordinate systems.
- A projected coordinate system such as universal transverse Mercator (UTM), Albers Equal Area, or Robinson, all of which (along with numerous other map projection models) provide various mechanisms to project maps of the earth's spherical surface onto a two-dimensional Cartesian coordinate plane. Projected coordinate systems are referred to as map projections.

Coordinate systems (both geographic and projected) provide a framework for defining real world locations.

2.5.1 Geometric Coordinate System

A geographic/geometric coordinate system is a coordinate system that enables every location on the Earth to be specified by a set of numbers or letters. The coordinates are often chosen such that one of the numbers represents vertical position, and two or three of the numbers represent horizontal position. A common choice of coordinates is latitude, longitude and elevation. The angles often are measured in degrees (or in grads) [17].

2.5.2 Projected Coordinate System

The Transverse Mercator Projection is very widely used, and is particularly appropriate for regions with a large extent in north-south direction but narrow extent in east-west direction. The Transverse Mercator is also the basis of a worldwide projection system known as Universal Transverse Mercator (UTM). This system divides the world up into 60 zones of longitude, each of width 6° . The zones are numbered from 1 starting at a longitude of 180°E , and increase eastwards [17].

Types of Coordinate Transformation

ArcMap supports three types of transformation: Similarity, Affine and Projective [17, 18]. Similarity based transformation scales, rotate and translate the data but will not introduce skew or rescale the axes; it requires a minimum of two displacement links. Affine transformation: requires a minimum of three displacement link, can scale, skew, rotate and translate data. Projective transformation: the most mathematically complex adjustment method requires a minimum of four displacement links.

2.6 Structure of geographic data

Geodatabase, dataset, object class and feature class are a part of GIS which helps to store and manipulate geographical data.

The geodatabase is classified in to two generations [19].

First Generation

In the first generation of geodatabases the spatial data is stored outside the DBMS system in separate files as we shown in Figure 2.2.

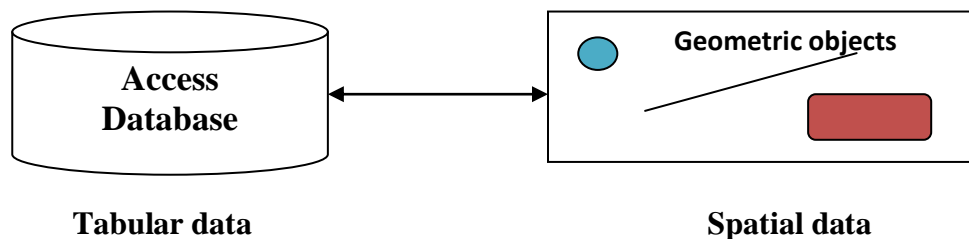


Figure 2. 2: 1st Generation Geodatabases

Second Generation

In the second generation of geodatabases the spatial data is stored inside the DMBS system in a separate column called GEOMETRY. Overall spatial data is linked and stored in the same location in tabular format in DBMS as shown in Figure 2.3.

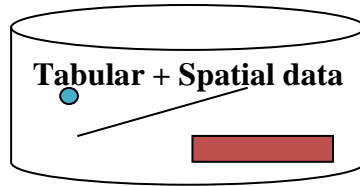


Figure 2. 3: 2nd generation Geodatabases

Types of Geodatabase

There are three different categories of geodatabases, namely: personal, file and ArcSDE. We will discuss each category in the following subsection.

Personal Geodatabase: a database system which used to store small size spatial geometries and non-spatial data.

File Geodatabase: a geodatabase which supports single user editing and uses a normal file structure to store medium size spatial information.

ArcSDE Geodatabase

This database is built on top of RDBMS system as shown in Figure 2.4. This kind of database is used to provide a multiuser environment via providing central spatial data storage location.

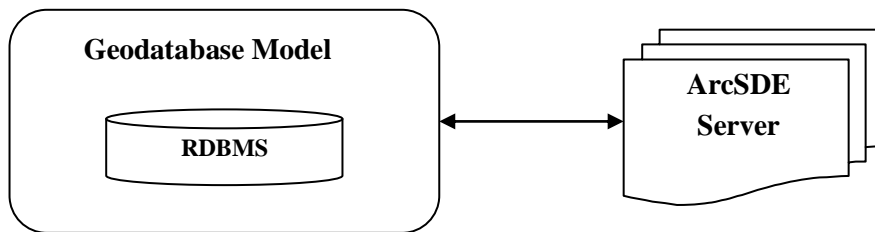


Figure 2. 4: ArcSDE Geodatabase

ArcSDE Service: Each ArcSDE geodatabase has an ArcSDE service, also known as an application server or a three-tiered architecture, conveys spatial data between GIS applications and a database [20]. The database may be any of the supported database management systems Oracle, SQL Server, Informix, DB2, or PostgreSQL. ArcSDE service contains a giomgr component to listens for user application connection requests and gsrvr component used to perform tasks for each tasks connected to the ArcSDE service.

Geodatabase transaction: A key element in database functionality is the transaction. A transaction represents a logical group of data-based operations that make up a complete operational task [21]. There are two types of database transactions: short or long.

Short Transaction: a transaction in which edit operations are completed in a matter of seconds. Examples would include automated bank teller transactions or record updates.

Long Transaction: Extended editing operations, which may involve many short transactions and a number of database editors, are referred to as long transactions.

Problems with short transactions

Although short transactions work well in situations where critical applications require immediate access to a consistent view of the data, they are not well suited to the type of editing tasks required when updating geographic data and have two basic limitations.

- **Lock escalation:** Row locks become page locks, page locks become whole table locks.
- **Deadlock situations:** Two transactions are waiting for each other to unlock data, preventing any further updates until the deadlock is resolved.

2.6.2 Two Phase Commit Protocol

Two phase commit protocol is a feature of transaction processing systems that enables databases to be returned to the pre-transaction state if some error condition occurs. A single transaction can update many different databases. The two-phase commit strategy is designed to ensure that either all the databases are updated or none of them, so that the databases remain synchronized [22].

Triggers and PL/SQL

A database trigger is procedural code that is automatically executed in response to certain events on a particular table or view in a database. The trigger is mostly used for maintaining the integrity of the information on the database [24].

The two main types of triggers are:

- Row Level Trigger: Executed before or after any column value of a row changes.
- Statement Level Trigger: Executed only once for the entire result set, but fires each time the statement is executed.

Procedural Language/Structured Query Language (PL/SQL)

PL/SQL is Oracle's procedural extension to SQL, the standard database access language that have built-in treatment of the relational database domain by adding procedural constructs to SQL, such as encapsulation, function overloading, information hiding, block structure, conditional statements, structured data and customized error handling[23]. PL/SQL also used for:

- Declare constants and variables
- Define procedures and functions
- Use collections and object types
- Trap runtime errors

2.6.3 Geodatabase spatial data editing techniques

There are three common spatial data editing techniques in geodatabase disconnected editing, versioned editing and non versioned editing.

a. Disconnected Editing

The disconnected editing operations allow you to replicate data of interest from a feature service. The data can then be edited locally (on the client) while disconnected from the server [25]. When connected, the client can then synchronize the changes with the server.

The following service resource operations are provided for disconnected editing:

- Create Replica
- Synchronize Replica
- Unregister Replica

Handling offline updates is another major issue for geospatial data gathering. Users often go into the field to collect data, where network connections are not reliable. Presently, the best method

involves copying the data to a mobile device and attempting to track changes. If the offline user makes edits while the central database is also changing that information, syncing the data when back online becomes extremely challenging.

A true distributed versioning system can smooth this process. Shifting the perspective from treating the mobile device instance as a copy of the data to approaching it as an active repository in itself enables changes to be made in a less tentative manner. With change tracking built in to the data format, changes can be synced when back online, with each change compared individually to the most current version of data in other repositories.

b. Versioned Editing

The two-tier version hierarchy is a more common implementation of versioning as it supports a more structured approach to workflow management [26]. Discrete work units related to specific projects, work on which may involve many edit sessions typically spanning a number of days, weeks, or in some cases months, can be maintained without affecting the DEFAULT version. Examples of these discrete work units could be a highway improvement scheme, the installation of a new phone service, or an ongoing maintenance project for a gas pipeline. When an editor has finished modifying the data, they or the SDE administrator can reconcile and post the version to the DEFAULT version. If conflicts are detected, they must be resolved in the usual way and the changes saved again during the edit session. The editor's version can then be deleted as required.

Pros

Simplicity: each work unit is logically segregated in the geodatabase. Supports long transactions, spanning many edit sessions, and the creation of alternative designs. This allows editors to develop proposals without affecting the production database. Creating a new version from the DEFAULT version protects the production view of the database from unintentional modification, individual work projects are integrated with the production database when completed and supports post processes.

Cons

As with any multitier version configuration, the more rows that are maintained in the version

delta tables, the greater the potential impact on version query performance. This overhead can be minimized by compressing the database regularly and updating the database management system (DBMS) statistics.

c. Non-Versioned Editing (Direct Editing)

The simplest approach to supporting multiuser access to a versioned geodatabase is for many editors to directly edit the DEFAULT version. This temporary version is accessible only to the current editor, and it automatically evolves through the succession of states created by each new edit operation. When the editor saves their work or ends the edit session, this temporary version is automatically reconciled with and posted to the default version.

Pros

Simplicity: this versioning workflow is probably most applicable to situations where the units of work are fairly small or where persistent design alternatives are not required. If no conflicts are detected, the edits are directly posted to the DEFAULT version without user intervention.

Cons

The DEFAULT version is constantly changing and is vulnerable to inadvertent or malicious modification. Specific action is required on the part of the database administrator to preserve a historical record of the changes made to the DEFAULT version. This workflow does not support long transactions, which typically span many edit sessions, or the creation of alternative design versions.

2.6.4 Geographic Datasets

There are three general types of geographic data models: vector, raster, and triangulation. In the geodatabase, they are implemented by three types of geographic datasets: the feature dataset, the raster dataset, and the TIN dataset. A feature dataset is a collection of feature classes that share a common coordinate system. A raster dataset can either be a simple dataset or a compound dataset with multiple bands for distinct spectral or categorical values. A TIN dataset contains a set of triangles that exactly span an area with a z value for each node that represents some type of surface. Generally the spatial data set used to handle object classes, feature classes, topology and relationship classes together.

Object Classes: An object class is a table in a geodatabase with which you can associate behavior. Example an object class is owners of land parcels.

Feature Classes and Topology: A feature class is a collection of features with the same type of geometry: point, line, or polygon. There are three categories of feature classes: simple, networked and topological [27].

Simple Features: Simple feature classes contain points, lines, polygons, or annotation without any topological associations among them. That is, points in one feature class may be coincident with, but distinct from, the endpoints of lines in another feature class. These features can be edited independently of each other.

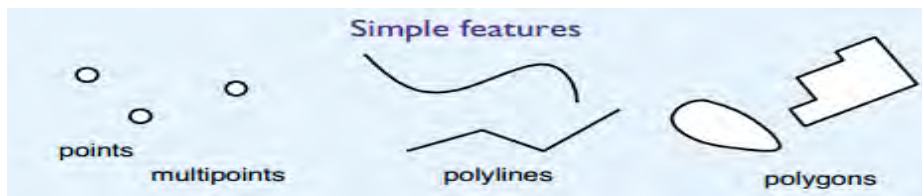


Figure 2. 5: Simple Features

Network features: Features can be connected in a network. A network contains edges that have nodes at their endpoints.



Figure 2. 6: Networked feature

Topological feature classes are bound within a graph, which is an object that binds a set of feature classes that comprise an integrated topological unit.

Relationship Classes: A relationship class is a table that stores relationships between features or objects in two feature classes or tables.

2.7 Utility mapping

Utility mapping means displaying maps of utility service providers underground infrastructure using mapping technologies [28]. In order to identify one utility underground infrastructure from the other they have the capacity to assign a unique color to represent underground utilities of different service providers.

Color coding system

Nowadays, public utilities are assigned a color in order to uniquely identify their infrastructures. The American Public Works Association encourages public agencies, utilities, contractors, other associations, manufacturers and all others involved in excavation to adopt the APWA Uniform Color Code, using ANSI standard Z535.1 Safety Colors for temporary marking and facility identification [29]. This marking guide provides for universal use and understanding of the temporary marking of subsurface facilities to prevent accidents and damage or service interruption by contractors, excavators, utility companies, municipalities or any others working on or near underground facilities. The colors below are industry standard and each color identifies a specific type of utility.

Table 2. 1: Color coding system

No	Color	Usage
1	Red	Electric power lines, cables or conduit, and lighting cables.
2	Yellow	Gas, oil, steam, petroleum, or other hazardous liquid or gaseous materials.
3	Blue	Water, irrigation, and slurry lines.
4	White	Pre-marking of the outer limits of the proposed excavation buried facilities.
5	Green	Sewers, drainage facilities or other drain lines.
6	Orange	Communications, cable TV, alarm or signal lines, cables or conduits.
7	Pink	Temporary Survey Markings.
8	Purple	Slurry and reclaimed.

Chapter Three: Related Work

The management of underground infrastructure using GIS spatial database engine is a recent technology. Scholars have conducted GIS base utility management researches using different approaches. Among these research works, some of the works that are more relevant to our work which are done using non versioned, versioned and disconnected editing approaches are reviewed and presented in this Chapter.

The GIS based approach for the design of a utility geographical information management system recognizes that GIS is the most robust software and database system to manage an inventory of geographically distributed assets such as: water and sewerage systems, electric and gas lines, roadways, bridges, traffic control, cable networks, etc. These resources should be fully integrated in order for an infrastructure management authorities and utility services to achieve maximum efficiency in its operations [30].

3.1 Locating and Management of Underground Utility

A method and tools, including software, for the development and operational use of precise utility location and asset information management is developed by Layne *et al.* [57]. However, this work used Ground Penetrating Radar (GPR) to locate different underground asset and it doesn't include underground utility spatial data editing.

Systems and methods provide for detection of one or more underground utilities is developed by Gary *et al.* [59]. Radar waves and seismic waves of about the same wavelength are generated and communicated into a subsurface. Radar and seismic response signals resulting from communication of the radar and seismic waves into the subsurface are concurrently received. Data associated with the received radar and seismic response signals are stored. One or more underground utilities within the subsurface is/are detected using the stored data. However, this work detects or locates underground utilities using GPR technology and it doesn't include underground utilities spatial data editing.

Huanhuan *et al.* [48] explore the application of AI techniques, in particular Bayesian data fusion (BDF), to automatically generate maps of buried underground infrastructures. Hypotheses about the spatial location and direction of buried assets are extracted by identifying hyperbolae in the GPR scans. However, this work also used GPR sensors to locate underground infrastructures and it doesn't include utilities spatial editing and authentication.

Ming *et al.* [60] explore building an Asset Management System by expanding the existing water model, which facilitates the horizontal assets, to integrate the vertical assets on top of it. However, this work only includes management of water utility.

Gerhard *et al.* [61] present an Augmented Reality (AR) system for aiding field workers of utility companies in outdoor tasks such as maintenance, planning or surveying of underground infrastructure. However, this work uses magnetic lenses and sensors to visualize 3D underground utilities map.

Mark *et al.* [62] present a solution for accurately mapping the exposed underground utilities, and for creating an underground utility database that holds all of the necessary information pertinent to underground asset management. The focus of this work is the development of a mapping system to enable the acquisition, assembly, manipulation and management of spatial data defining the location of underground utility services. However, this work doesn't include utilities data editing and authentication.

Ghazali *et al.* [63] present a study to determine the real-time location of the subsurface utilities through the integration of Ground Penetrating Radar (GPR), Global Positioning System (GPS) and GIS. The GPS use to retrieve the location of the utilities obtained by the GPR and represented by x and y coordinates value. The GIS data model is mapped in the mobile device such as Personal Digital Assistant (PDA) as a base map of the study area. The results obtained are digital map of the subsurface utilities that integrated with PDA and the location of the utility is verified between the reading of the GPS and GIS base map. However, this study used a GPR technology to locate underground infrastructures.

Wang *et al.* [64] introduces every function and the key technology of the system in detail, such as seamless integration of GIS of water supply pipeline network and hydraulic model which

based on building pipeline network concise model dynamic and use the hydraulic calculation function to guarantee the authenticity of hydraulic model, hydraulic model which can help to simulate the whole system and analyze the condition of pipeline network, the model of pipe blowout statistical can help operator to know the condition of water pipe every segment in the system and forecast the events of pipe blowout, and according to the requirements of system, the fast locating algorithm was modified to reduce the time of searching objects. All these important technologies can strengthen the security, improve the speed of locating objects and help operator to analyze the pipeline condition.

To solve the monitoring and locating problems of the underground booster and leakage of the water supply network, a remote leakage monitoring and locating system based on GSM/GPRS network is designed in [31]. The data transmission is realized by GSM/GPRS network and the status of tap water pipe network is monitored by a web-based spatial information system. However, the limitation of this work is that it does not include other underground assets like electric and telecommunication lines.

Autonomous robotic mobile platforms realizing vision include the electromechanical design of the robot itself, integrating sensors that are able to estimate the physical properties of the infrastructure and its autonomous operation [38]. However, this work used GPR sensors to locate underground electric power infrastructure.

Implementation of mobile robots for continuous autonomous monitoring of underground infrastructures can provide a cost-effective means of gaining accurate information for maintenance planning [39]. However, this work doesn't include underground utility spatial data editing and authentication.

Underground pipe inspection represents one of the last frontiers for Ground Penetrating Radar. However, this needs a reliable apparatus to keep the antennas in constant contact with the pipe wall, CCTV to view the output and Ground Penetrating Radar and this approach is very complex.

A novel, semi-autonomous robotic sensor platform has been developed by Bingjing *et al.* for monitoring underground, power distribution cable systems [40]. A segmented, legged modular

configuration allows the robot to traverse cables with a diameter of four to eight centimeters and negotiate obstacles along its path. However, this work only includes monitoring underground power distribution infrastructure failures and it doesn't include underground utility spatial data editing and authentication.

A lot of research works are done on underground utilities leakage monitoring which used to detect leaks in underground infrastructure [34, 35, 41]. However, these works don't include underground utility spatial data co-editing and authentication.

3.2 Spatial Data Editing

There are a lot of works that have been done on spatial data editing. The relevant works related to our work are described below.

Janakiraman *et al* [44] described a way by which near-real time geospatial data made available for decision support systems. Most often ownerships are ignored, and geospatial editing is carried out by copying relevant feature classes into a single repository. Versioned editing is carried out to transact a geospatial transaction. Edited feature classes are then distributed through replication to data consumers.

Accessing widely distributed geospatial database repositories through a web map portal for browsing and querying is prevalent already. In such portals, raster and vector features are made available through web services. Direct web enabled editing based on the ArcGIS server has become available and is used for simple single feature class updates [45]. However, web based editing of versioned spatial feature classes is not prevalent yet.

ArcGIS also introduced the concept of disconnected editing where a spatial data editor could take a version of the data repository and continue editing the data remotely [25]. On completion of editing, the edits are reconciled and merged with the main repository. The method is for a single repository, however it offers distributed editing. Further, for disconnected editing with mobile devices, the format of the data was changed to simpler shape-file, which really is not suitable for enterprise situations. Such a versioned web-enabled model for editing has also been proposed in the context of real-time collaborative editors [46] and also of

collaborative CAD [47]. These works, however, do not consider the multi-level feature classes existing in geospatial editing.

3.3 Summary

The works described in review of underground utility management in Section 3.1 above are bases in the process of building underground utility spatial data co-editing and authentication systems. Earlier works presented, however, to identify what infrastructures are located underground, most of them used Ground Penetrating Radar (GPR). GPR is a geophysical method that uses radar pulses to image the subsurface [43]. This nondestructive method uses electromagnetic radiation in the microwave band (UHF/VHF frequencies) of the radio spectrum detects the reflected signals from subsurface structures [37]. It is used for locating and mapping underground utility lines and has been the subject of much on-going research conducted by both military and commercial service providers. Unfortunately, GPR is not an effective locating tool in all areas. GPR has its own limitations like:

- It does not work equally well in all soil types. GPR works best in soils that are non-conductive. In general, clay soils inhibit the performance of the GPR signal. Sandy or gravelly soils are generally ideally suited to the method.
- Considerable expertise is necessary to effectively design, conduct, and interpret GPR surveys.
- The relatively high energy consumption can be problematic for extensive field surveys.
- It is labor intensive and very expensive.

Our proposed system does not use the Ground Penetrating Radar to locate service providers'' underground infrastructures.

Moreover, works presented in terms of applicability in utility service providers did not address underground infrastructure damages at the required level of importance in GIS environment. Ways of handling underground infrastructure information of utility service providers and the protection of underground infrastructure from damage without using GPR technology were not considered. Previous works discussed under Section 3.2 didn't consider underground utility map co-editing and authentication by using GIS latest editing approaches advantages. Therefore, this

work also focuses on embedding integrated underground utilities co-editing and authentication functionalities using the components of underground utility management general architecture to be analyzed.

Chapter Four: Design of GIS Based Multi-user Underground Utility Map Co-editing and Authentication

This Chapter describes the design of a model for multi-user underground utility map co-editing and authentication using versioning approach. It discusses a proposed model and architecture of GIS based utility management for the protection of infrastructures from damage. It also shows the proposed system spatial data version editing workflows monitoring mechanism authorities to have up to date infrastructure map information.

4.1 Overview of GIS Based Underground Utility Management

GIS based utility management is an application approach leveraging the Esri ArcGIS Geodatabase. GIS has been specifically used in the area of underground infrastructure management like road, water pipeline, and electricity cable and telecommunication.

Utility monitoring systems require a proper spatial data acquisition, spatial data analysis and management of changes to ensure delivery of services with the maximum required intelligence. Utility mapper, version manager, version editor, topological relation checker and transaction manager can be seen as the overall components in the proposed architecture.

An overview of the proposed architecture is shown in Figure 4.1. A Multi-user Underground Utility Map Co-editing and Authentication system (MUUMCA) is comprised of components such as spatial data acquisition, spatial data preprocessor, version manager, version editor, utility mapper, Geodatabase design, transaction manager and topological relation checker components. Authorities' utility data and spatial data collected using GPS are accepted by spatial data acquisition component. The spatial data preprocessor prepare and clean data that are acquired from spatial data acquisition component. Then the spatial information stored and managed by geodatabase component. Version manager helps the system to create a version of the original geodatabase and the version will be edited by version editor component. Topological relation checker helps to make sure what service provider affected by the change and this long transaction will be managed by transaction manager component. The details of the components of MUUMCA are provided in Section 4.2.

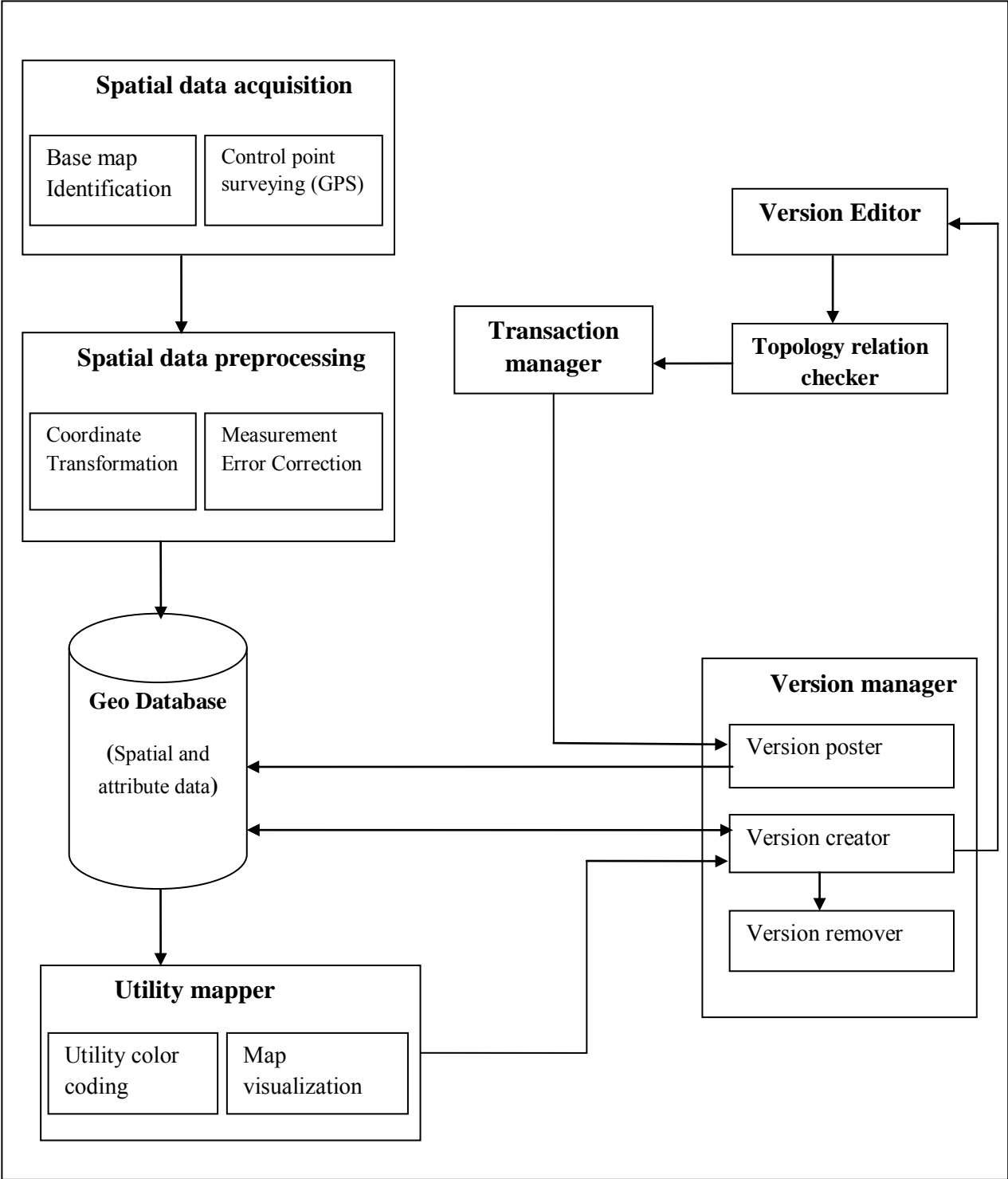


Figure 4. 1: General Architecture for MUUMCA

4.2 Major Components of the General Architecture

As described at the beginning of this Chapter, the GIS based underground utility map co-editing and authentication model designed in this thesis has six different components. The responsibilities of each individual component of MUUMCA in relation to the other components are discussed in detail in this section.

4.2.1 Spatial Data Acquisition

The first component of the MUUMCA is spatial data acquisition which is used to collect or acquire utility spatial data of different type from different sources. This includes both primary spatial data collection and secondary spatial data collection. Primary spatial data collection is a direct data acquisition methodology that is usually associated with some type of in-the-field effort. In the case of vector data, directly captured data commonly comes from a global positioning system (GPS) or other types of surveying equipment. Secondary spatial data collection is an indirect methodology that utilizes the vast amount of existing geospatial data available in both digital and hard-copy formats. Prior to initiating any GIS effort, it is always wise to mine online resources for existing GIS data that may fulfill mapping needs without the potentially intensive step of creating the data from scratch. The spatial data acquisition component has two sub components: utility map identification and control point surveying components. The utility map identification component is used to acquire underground utility maps of utility service providers and identifies utilities map format, scale, extent and projection of each service provider. The control point surveying sub component is used to acquire ground control points to georeference or to transform utilities map into a known coordinate system and to evaluate the accuracy of service providers utility map using GPS device. Gathering the essential georeferenced data is a paramount step because it provides data for new planned systems. Besides, it enables the data to be more accurately and precisely produced.

4.2.2 Spatial Data Preprocessing

Spatial data preprocessing is an important step in the underground utility map co-editing and authentication process. The phrase "garbage in, garbage out" is particularly applicable to GIS based utility management systems. Spatial data goes through a series of steps during

preprocessing: spatial data cleaning, spatial data integration, spatial data transformation and spatial data reduction. Spatial data cleaning is used to cleanse utilities spatial data through processes such as filling missing values, smoothing the measurement error, or resolving the utilities spatial data incompatibility. For utilities held in a digital format, the differences in data systems, structures and formats limits the ability to integrate data from different utilities effectively. Spatial data transformation is used to transform the acquired underground utility maps of service providers to a known coordinate system. The spatial data integration step is used to put spatial data with different representations together and conflicts within the data are resolved. Spatial data reduction step helps to present a reduced representation of the utilities spatial data in a geodatabase. The spatial data preprocessing component consists of two sub components: coordinate transformation and measure error remover components to clean and prepare utilities spatial data that we got from spatial data acquisition component for further processing.

Coordinate Transformation

Maps show us where things are in relation to one another. This requires a method of determining position on the surface of the Earth, a process known as spatial referencing or geo-referencing. The method by which georeferencing is carried out is very important as this will largely determine the accuracy of any map that is produced. Utility map georeferencing is accomplished by choosing ground control points a place where utilities are installed. These points are chosen as good as possible to represent the map coordinate set. The coordinate transform component used to assign a coordinate system and georeference utilities map of service providers.

Measurement Error Remover

One of the commonest errors when digitizing data occurs when there is a slight inaccuracy in the start or end point of a line. This can result in the line work not being correctly joined up. The line can form undershoot or an overshoot. Although these errors can be difficult to detect by the human eye, they prevent the GIS from understanding the fact that these two features are actually joined to each other. The measurement error remover component is used to resolve or smooth the topological errors of utilities spatial data that we acquired from spatial acquisition component.

4.2.3 Design of Geodatabase

Geodatabase is the physical storage of geographic information, primarily using a database management system (DBMS). Geodatabases have a comprehensive information model for representing and managing geographic information. This comprehensive information model is implemented as a series of tables holding feature classes, feature datasets, and attributes. The MUUMCA geodatabase component used to store underground utilities map data of the service providers that acquired from spatial data preprocessing component. In addition to utilities spatial data, the geodatabase component is used to store non-spatial data and the relationship between spatial and non-spatial data like the owner and the layer of a utility service provider. Geodatabase has tables those record version changes are referred to as the delta tables. These delta tables record any changes (new, modified, or deleted records) made to that table or feature class at each state of the geodatabase.

4.2.4 Version Manager

The version manager component comprises three sub components version creator, version poster and version remover.

Version Creator

This sub component in MUUMCA helps the system to create a new version from the default or original geodatabase. Version creation is the first phase to implement any spatial data editing system using versioning approach.

Version Poster

Version posting is the final step of versioning approach. Posting version meaning the change that has been done by version editor will be posted on the original/default geodatabase. The version poster subcomponent is used to store the spatial data that exist in delta table to base table of the original geodatabase.

Version Remover

The version remover sub component is used to remove or delete the child version after completion of its task. Unlike other versions, the DEFAULT version always exists and cannot be

deleted. But we can maintain and update the DEFAULT version over time by posting changes to it from other versions. The DEFAULT version is the root version and, therefore, the ancestor of all other versions.

4.2.5 Transaction Manager

A transaction symbolizes a unit of work performed within a database management system (or similar system) against a database, and treated in a coherent and reliable way independent of other transactions. A transaction generally represents any change in the geodatabase. There are two types of geodatabase as we described in chapter two: short and long transaction. A short transaction can be managed by the system automatically whereas a long transaction is a transaction which spans a long period of time and committing of the change is based on the response of others. MUUMCA transaction manager is responsible for managing and coordinating transactions across one or more resources. The transaction manger component contains a two phase commit protocol subcomponent.

Two Phase Commit Protocol

Two phase commit protocol is a feature of transaction processing systems that enables geodatabases to be returned to the pre-transaction state if some error condition occurs. A single transaction can update many different databases. The two-phase commit strategy is designed to ensure that either all the changes are committed or none of them, so that the geodatabases remain synchronized. Figure 4.2 shows the algorithm how transaction manager is designed.

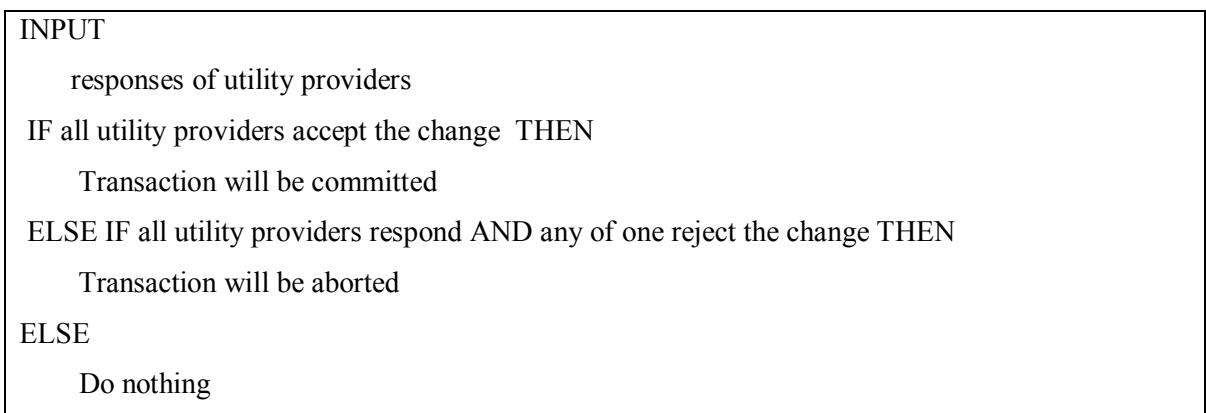


Figure 4. 2: Algorithm of transaction manager

4.2.6 Version Editor

Once the version creator component creates the version of the default geodatabase, the utility provider edits its own underground utility spatial information. The version editor component is responsible for editing underground utility spatial data of the version which acquired from the version creator component. The version creator and editor components play a vital role to design a multi-user concurrent spatial data editing model. All changes done by the version editor component is temporarily stored in the geodatabase delta tables.

4.2.7 Topological Relationship Checker

The topological relationship checker component is used to check the topological relationship between the proposed underground utility spatial data edited by the version editor component and the utility maps of all service providers in the default geodatabase. Feature class of each service provider is represented by using multi line feature classes. The basic topological relationships that can exist between multiline feature classes are “intersection”. This components is responsible to identify which service provider underground infrastructure is affected by the proposed underground utility installation that have been done on version editor component. Figure 4.3 shows the algorithm how topological relationship checker is designed.

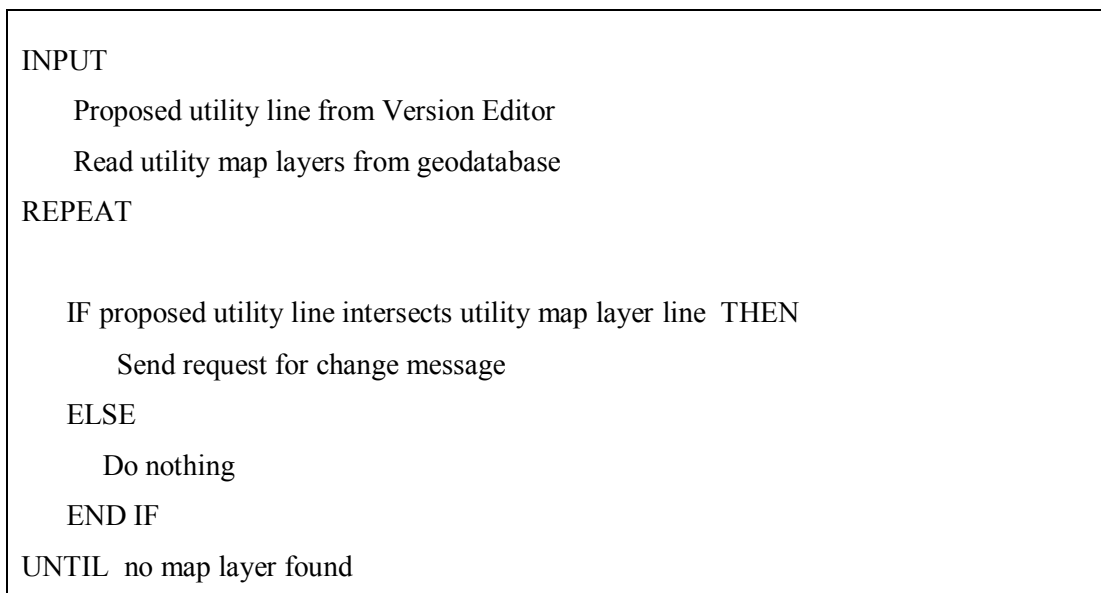


Figure 4. 3: Algorithm of topological relationship checker

4.2.8 Utility Mapper

Maps are uniquely capable for sharing knowledge about our world in many ways. MUUMCA utility mapper component is used to display maps of underground infrastructure in a well designed manner using recent mapping technologies. The utility mapper component contains two sub components named utility color coding and utility map visualization components. The utility color coding sub component is responsible for representing a unique color for each underground utility of service providers based on APWA standard that we described in Chapter Two. The utility map visualization component is used to display or visualize integrated underground utility maps of utility service providers in an attractive way.

4.3 Spatial Data Editing Workflow

The utility spatial data editing workflow consists of four basics steps: versioning, version editing, and posting. Figure 4.4 explains the process of editing a version and authentication in MUUMCA.

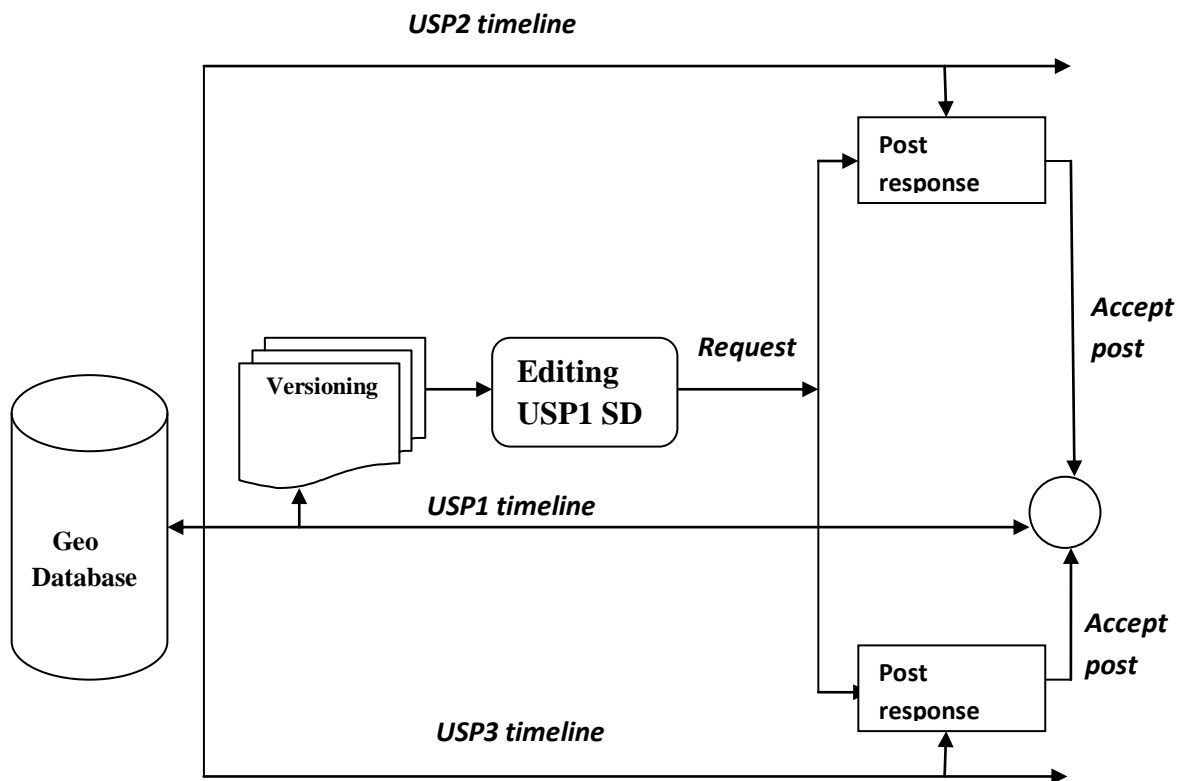


Figure 4. 4: MUUMCA spatial data editing workflow

MUUMCA spatial editing work flow in Figure 4.4 shows how underground utility editing and authentication of different service provider is done. The editing workflow description follows:

- The geodatabase component is responsible for storing underground utility map data of service providers.
- The versioning process is used to create a version from the original database. The utility service providers which create a version from original geodatabase act as the monitor or coordinator of the transaction process. In Figure 4.4 Utility Service Provider2 (USP2) is the coordinator of the change and Utility Service Provider1 (USP1) and Utility Service Provider3 (USP3) are the service providers affected by the change done on USP2 underground utility.
- The version editing process is responsible for editing underground utility spatial data and sends a request for post message for the affected utility service provider USP1 and USP3.
- The post response process is used for the affected utility service providers to send/post their response message to the coordinator.
- Finally, if the coordinator get accept post message from all affected utility providers, the change will be committed in the original geodatabase else the change is aborted.

Chapter Five: Implementation and Evaluation

In this Chapter, the implementation of web based multi-user underground utility map co-editing and authentication system for the case of Addis Ababa city utility service providers along with the experimental results is described. The design of our work is demonstrated by the implementation of a prototype system. The development environment and the tools that are used for the development of the prototype are also described in this Chapter.

5.1 Development Environment

The development environment that is used in the development of Multi-user underground utility map co-editing and authentication is described below. Our system is developed and tested on a single personal computer of 2.4GH CPU speed, 4 GB RAM, 500GB hard disk data storage capacity, with Microsoft Windows 7 operating system.

5.2 Development Tools

Several tools and technologies were utilized for the purpose of developing the prototype implementation. The following are lists of programming, ArcGIS middleware, utility mapping, spatial database management, and client application programming interface which are used in the prototype implementation.

Java Development Kit 1.7

Java programming language is used to write the implementation of the prototype. The Java™ Programming Language is a general-purpose, concurrent, strongly typed, class-based object-oriented language. We installed Java Development Kit version 1.7 (JDK1.7) on a windows environment. Then we used Java programming language for implementing various components of the multi-user underground utility map co-editing and authentication architecture.

NetBeans IDE 6.5

NetBeans is an integrated development environment (IDE) for developing primarily with Java, but also with other languages, in particular PHP, C/C++, and HTML5. It is also an application platform framework for Java desktop applications and others. We used it for writing, compiling

and running the java codes written for the underground utility map co-editing and authentication system.

Oracle Express Edition 11g database

Oracle Express Edition 11g database management system is a widely used open source relational and object oriented database management system and supports large spatial data storage and analysis. We used it to store each utility service providers' underground utility spatial data and non-spatial data in the prototype development.

ArcSDE 10 for oracle11g

Spatial Database Engine (ArcSDE) is a server-software sub-system produced and marketed by ESRI that aims to enable the usage of relational database management systems for spatial data. The spatial data may then be used as part of a geodatabase. It used for developing an application which supports multi-agent spatial data editing and concurrent spatial data editing.

GeoServer 2.5

GeoServer is an open-source server written in Java which allows users to share, process and edit geospatial data. We used it to publish utility maps using Web Map Server version 1.3.

ArcSDE API for Client

Geotools ArcSDE Application Programming Interface is a java application programming interface plug-in which helps to access ArcSDE geodatabase using java programming language.

ArcGIS 10 desktop

ArcGIS is used for creating and using maps; compiling geographic data; analyzing mapped information; sharing and discovering geographic information; using maps and geographic information in a range of applications; and managing geographic information in a database. We used it for preprocess underground utilities maps of service providers like coordinate transformation, measurement error correction, georeferencing and map scale and extent correction.

OpenLayers 3

OpenLayers is an open source JavaScript library for displaying map data in web browsers. It provides an API for building rich web-based geographic applications. Openlayer version 3 client web mapping application is used to displays each utility service provider underground utility map data.

GPS

The Global Positioning System (GPS) is a space-based satellite navigation system that provides location and time information in all weather conditions, anywhere on or near the Earth where there is an unobstructed line of sight to four or more GPS satellites. GPS is used for collecting coordinates or ground control points for georeferencing a CAD based utilities map of utility service providers.

5.3 Components of MUUMCA

In order to implement the GIS centric underground utility monitoring system, we have carried out the following tasks.

5.3.1 Spatial Data Acquisition

The spatial data set for the experiment consists of four ArcSDE utilities map information: ethio telecom has 46167 rows of data, ERA has 9093 rows of data, AAWSA has 4304 rows of data and EEPC has 2149 rows of data a total of 61715 rows of data. In order to georeference CAD based maps of ETC and EEPC, we collected 11 control points on 11 ETC manholes and 9 control points on 9 EEPC manholes with a total of 20 control points. In order to georeference map layers using similarity transformation technique, ten to twenty control points are recommended [25]. While only 9 control points are gathered, in order to transform electric map layer because of lack of visible actual reference or control points on the ground. Manholes are a wider hole that helps technician to enter inside and install or maintain the infrastructures that exist underground. Every manhole of ETC has a device which is used to connect fiber optic and coaxial lines. The manhole of EEPC has transformer to connect medium voltage and low voltage cables. Control points are collected for manholes those are found beneath roads from Sidist kilo Yekatit 12 Adebabaye to Arat kilo, to Shiro meda and to Arada Georgis roads using GPS

devices. The control points we collected are represented using projected coordinate system and stored in MS Excel application software. The reasons why we chose Projected Coordinate System is that it represent spatial information in metric and existed utility maps were also represented using Projected Coordinate System. The collected utilities map layers are shown in Figure 5.1.

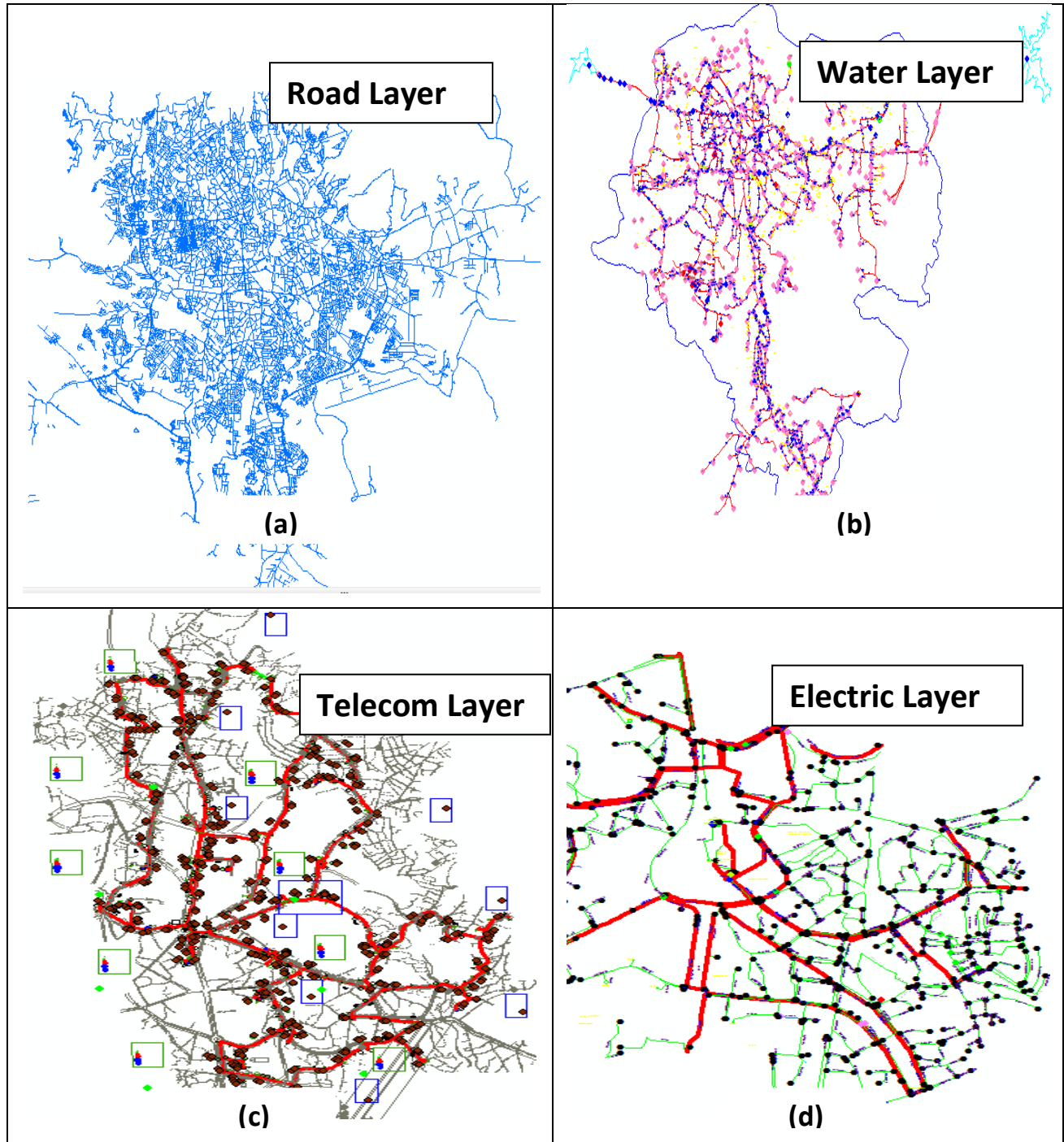


Figure 5. 1: Utility maps of service providers

The above four utilities map layers shown in Figure 5.1 have different file formats and map scales. The file format and map scales of each authority underground utility map layers are described in Table 5.1.

Table 5. 1: File formats and map scales of authorities’ utility layers

NO	Layer name	Authority	Map format	Map scale(<i>inch:inch</i>)
1	Roads	ERA	GIS based+georeferenced	1: 207,209
2	Water pipeline	AAWSA	CAD based+georeferenced	1: 718,494
3	Telecom line	ETC	CAD+non-referenced	1: 95,599
4	Electric line	EEPC	CAD+non-referenced	1: 55,516

The quality of spatial data we acquired plays a great role to develop an efficient GIS application. The importance of Geographic Information System spatial data quality can be expressed by famous computer industry proverb “garbage in, garbage out”. A GIS system is only as good as the data used to create it [23]. Data quality roughly means how good the data are for a given application. Use of inappropriate data in a GIS map may lead to misleading results and erroneous decisions, which may erode public confidence or create liability.

The utility map layers we got from different authorities have topological errors, represented with different map scales, different file formats and not projected as well and those might have direct impact on the accuracy of the final GIS system. In order to increase the quality of the acquired utility map, we preprocessed it in MUUMCA spatial data preprocessing component. One of the basic spatial data preprocessing we have done while we develop MUUMCA spatial data preprocessing component is coordinate transformation or projection as we describe in Section 5.3.2. To transform maps from one CS to another effectively, the accuracy of the control points we collected plays a vital role.

This study used Garmin® GPS device to acquire control points to transform unprojected utility maps. According to [22] GPS has become commonplace because of its ease of use and accuracy in determining location of public utilities. Today's GPS receivers are extremely accurate, but certain atmospheric factors and other sources of error can affect the accuracy of GPS receivers. Garmin® GPS receivers are accurate to within 15 meters on average. In order to improve the

accuracy of the spatial data, we collected control points with different atmospheric condition and used areas refrain from different sources of error of GPS data collection like we took control points far from tall buildings, trees etc. According to [24], taking GPS points of an area with different atmospheric condition and take points away from different sources of errors; and finally take the average may lead to a position with improved accuracy. For this reason, we collected control points of an area with three different days of different atmospheric condition and took the average of the collected spatial point data to improve the accuracy.

5.3.2 Spatial Data Preprocessing

In this study to clean and create a quality spatial data we have done different spatial data preprocessing tasks.

Map format and scale correction

The first step we did in spatial data preprocessing component is file format conversion. The underground utility maps data we acquire have a different format, scale and projection as we described in Table 5.1. In order to make maps to have the same format, we converted CAD based DWG format files to shapefile by using ArcGIS desktop ArcToolbox toolbar conversion tool component. Then every converted and pre-existed GIS based underground utility maps of each service provider need to have the same map scales and we represented underground utilities map with a map scale of 1inch:24,000 inches.

In [26], compatibility is considered as one of the basic parameter to have a quality spatial data. The term compatibility indicates that it is reasonable to use two data sets together. Maps digitized from different sources at different scales might be incompatible. In this study to get rid of compatibility issues, the collected spatial data with different source, map scale and file format are converted into a spatial data set which contains utilities maps with the same map scale and file format.

Map coordinate transformation

The other task we have done in MUUMCA spatial data preprocessing is coordinate transformation. All the converted and pre existed GIS based underground utility maps of each authority need to have the same projection or coordinate system. There are two basic kinds of

Coordinate System: Geometric Coordinate System and Projected Coordinate System as described in Chapter Two. We used Projected Coordinate System because it represents map information in metrics (meter or kilometer). After we assigned the coordinate system, shapefiles which are not georeferenced are georeferenced. In order to georeference utilities map, we used the acquired control points those we got from data acquisition component and added them in to ArcMap10 desktop application. ArcMap has a Georeferencing toolbar which used to georeference or transform a map from unknown or known CS to another using the input control points. ArcMap spatial adjustment tool uses three coordinate transformation techniques to transform unknown coordinate or one coordinate system to another: similarity, affine and projective as described in Chapter Two. The utility data we had are CAD based and; CAD based transformation is based on the similarity transformation method; it is two points transformation that support rotation and uniform scaling.

In this study, the acquired telecom and electric map layers have no known coordinate system. In order to define the transformation, we collected 11 control points for ETC and 9 control points for EEPC as we described in Section 5.1.1. The technique we used to define the coordinate system is similarity based transformation. Transformation is implemented by creating a displacement link between two actual ground control points with high level of accuracy and two reference points on utility map of the same areas. A good transformation is a transformation which has smallest residual error from the link tables. The link table contains: displacement linkId which basically is used to uniquely identify a link from another link , X source, Y source of the reference points coordinate(longitude, latitude) values on the map and X destination and Y destination of actual ground control points coordinate(longitude, latitude) values and the residual error. Residual error is a statistical measure of how well a set of transformed control points match the positions of the same points in a target data set. Residual error is calculated by computing root mean square error of source and destination coordinate values. Root Mean Square Error is the average of the distances (also known as *residuals*) between each pair of control points. In [34], the root mean squared error (RMSE) is employed to quantitatively evaluate coordinate transformation, and this metric is defined as follows:

$$RMSE = \sqrt{\frac{\sum_{k=0}^{n-1} [(x_k - \bar{x})^2 + (y_k - \bar{y})^2]}{n}}$$

Where (x_k, y_k) denotes the coordinates of the reference points on the map, $(k=0 \dots n-1)$ are the number of points and (\bar{x}, \bar{y}) denotes the coordinates of the actual ground control points those we got from GPS survey.

In this study, to evaluate whether transformation of coordinate system is done correctly or not, we selected control points that scored a minimum RMSE or Residual Error. Table 5.2 shows RMSE values of telecom layer coordinate transformation using Sidist kilo yekatit 12 and Arat kilo monuments as ground control points.

Table 5. 2: Evaluation of a telecom layer coordinate transformation by RMSE/RE

ID	Control and reference points	X Source	Y Source	X Map	Y Map	Residual Error
1	MH_E1b	473777.59	999664.74	473778.35	999665.05	0.82079
2	MH_I5	473753.50	999704.01	473751.41	999705.74	1.91846
3	MH_G1	473991.34	998492.89	473993.49	998490.32	2.369345
4	MH_E1a	473798.22	999680.19	473799.65	999678.12	2.51591
5	MH_E1d	473792.07	999517.34	473790.83	999513.02	2.60599
6	MH_I3	473622.34	999746.52	473620.41	999749.65	2.60017
Average RMSE=2.13844 meters						

In this study, accuracy of a coordinate transformation is evaluated using a RMSE metric. As we showed in Table 5.2 coordinate transformation of telecom layer is tested using six randomly selected reference points and the average residual error scored is 2.13844 meters. This implies that, coordinate transformation is done accurately.

Spatial data clipping

In this study, spatial data clipping is used to create smaller data set from larger data set we got from spatial acquisition component and it helps maps to have similar map extents. This is particularly useful for creating a new feature class also referred to as study area or area of interest (AOI) that contains a geographic subset of the features in another, larger feature class. Figure 5.2 shows how to create smaller feature class from the larger road feature class using rectangular clipper feature class. The area of the clipper feature class is the Area of Interest where we tested our system.

In this study, to clip feature classes we used ArcMap ArcToolbox Analyst tools component. This tool has a function clip to extract smaller feature class from larger feature class. To clip the input feature classes, first we created a rectangular polygon feature class with defined coordinate system known as clipper feature class. The rectangular clipper feature class has an extent of left: 471080.15 m, bottom: 994911.08 m, right: 474840.972705 and top: 1000280.82 m; and has an area of 19768559.32 square meters. Then we added the input road feature class in ArcMap and overlay the rectangular clipper polygon feature class on the input road feature class as shown in Figure 5.2a. The input road feature class is represented using a light blue color and the clipper feature class is a rectangular polygon feature class on the road feature class which is represented using red color before clipping as we have shown in Figure 5.2a and Figure 5.2b shows the output of road feature class after we performed clipping.

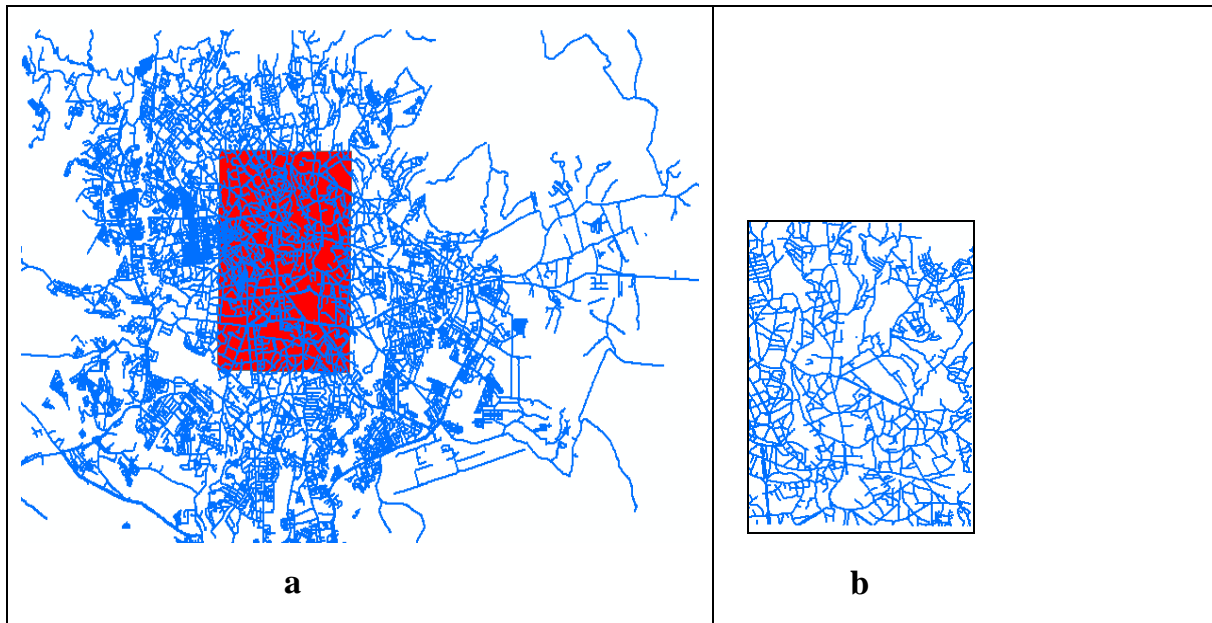


Figure 5. 2: a) Road utility layer before clipping. b) After clipping

After all feature classes are clipped, we stored them in ArcSDE geodatabase feature data set. Each feature dataset in geodatabase has a single reference frame, which includes the map projection and map extent [27]. Before clipping, feature classes of each authority had different map extents or map bounds after clipping is done every feature classes of a feature data set have similar map extents, which improves the quality of the spatial data in a spatial data set.

Topological error correction/smoothing

The most accurate maps created by a GIS have some deficiencies. These deficiencies occur due to “Errors” that may have taken place at different stages of GIS implementation. These errors reduce the accuracy of the map generated. However, by use of well defined and controlled procedures these errors can be avoided. One of errors in GIS is topological error which occurs often during the digitizing process. The two basic topological errors that may exist in polyline feature classes are overshooting and undershooting. Overshoots and undershoots happen when the line digitized doesn’t connect properly with the neighboring line it should intersect with.

In this study, one of the basic tasks we have done in spatial data preprocessing component is measurement or topological error correction. ArcMap 10 has topology editing tool component to correct or smooth topological errors. In order to correct topological errors, first we created a topology feature class with default cluster XY tolerance value 0.001meter for the feature data set of ArcSDE geodatabase using ArcMap ArcToolbox data management tool. The XY tolerance is an extremely small distance used to resolve inexact intersection locations of coordinates during clustering operations. It is the minimum distance allowed between XY coordinates before they are considered equal. After we created the topology, we added topological rule for the created topology. ArcSDE geodatabase feature data set has over 25 topological rules. The basic topological rule for polyline feature class is “Must Not Have Dangles”. Dangles are lines that are not connected but should be. Then we added the feature classes of each authority to check their topological errors using the rule we set in topology feature class. Table 5.3 shows the number of topological errors of the four utility feature classes we got while validating feature classes using “Must Not Have Dangles” topological rule.

Table 5. 3: Topological error of underground utility feature classes

No	Feature class	No of topological errors
1	Road	664
2	Water	145
3	Telecom	262
4	Electric	24

The total topological errors of the four feature classes are 1095, and out of them 80 % are undershooting topological errors and the remaining 20 % are an overshooting topological errors.

In this study to fix topological errors of feature classes in a data set, we used ArcMap topology editing Snap and Trim line error fixing components. The Snap fix will snap dangling line features to the nearest line feature within a given distance. If no line feature is found within the distance specified, the line will not be snapped. Snap fix searches for endpoints to snap to first, then vertices, and finally to the edge of line features within the feature class. Figure5.2.2. shows how a sample undershooting topological error of each feature class is resolved by using Snap error fix component with snap or dangle length of 15 meter.

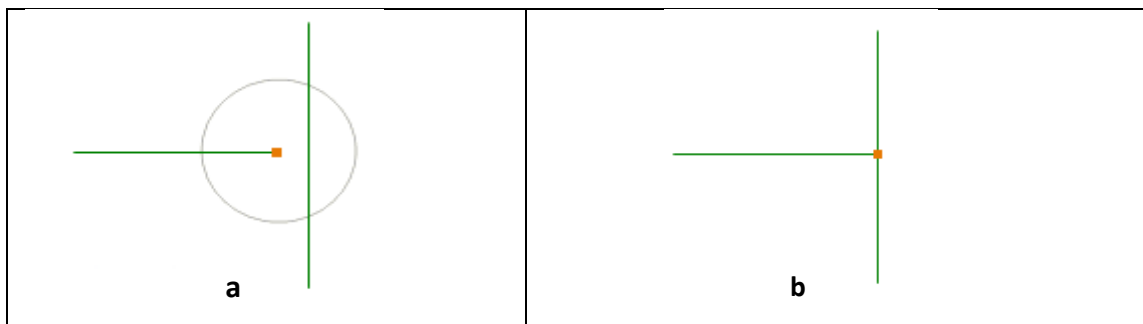


Figure 5. 3: a) before snapping b) after snapping feature class with snap length of 15 meters.

The Trim fix will trim dangling line features if a point of intersection is found within a given distance. If no feature is found within the distance specified, the feature will not be trimmed, nor will it be deleted. Figure 5.3 shows how a sample overshooting topological error of each feature class is resolved by using Snap error fix component with snap or dangle length of 15 meter.

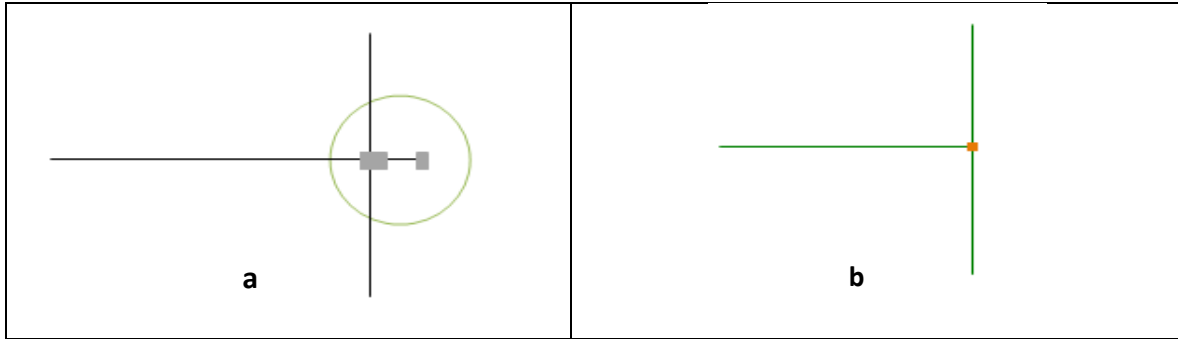


Figure 5. 4: a) Before trimming b) after trimming with dangle length of 15 meters.

5.3.3 Building a Geodatabase

After the spatial data preprocessing is completed the data is stored in ArcSDE geodatabase by using ArcCatalog 10 desktop application. ArcCatalog has a component used to connect SQL, Oracle and Informix database management system with ArcSDE application. In this study to store spatial data of each authority, we used oracle database management system. Because it can stores large amount of spatial data and supports spatial data analysis. After the connection between Oracle DBMS and ArcSDE middleware application is built, we created a feature dataset which helps to store feature classes together with the name “UtilityFDS” and import all preprocessed maps of each authority into default ArcSDE geodatabase. The geodatabase not only contain spatial information, it also has attribute data like the owner of each underground infrastructure. In order to manage attribute data, we designed attribute table for each service provider and we created the relationship between layers and the authorities who granted to edit a given spatial data. In addition to feature classes and attribute tables, there are two delta tables: Add and Delete tables which basically are used to implement the versioning approach. The two delta tables are created automatically when registering a feature data set as versioned. If a feature data set is registered as versioned implies any one can create a version of the original geodatabase and edit the spatial information of that feature data set objects. The Add delta table is used to store underground utilities proposed line spatial data temporarily and Delete table used to store the proposed removed line spatial data temporarily. Figure 5.5 shows the instance of Add delta table with stored temporary data and used to accept posts from different authorities.

OBJECTID *	SHAPE	COORDINATOR	WATER_RESPONSE	TELE_RESPONSE	ID	SHAPE.LEN
321	Polyline	ROAD	NIL	NIL		0.149188369089488
322	Polyline	ROAD	NIL	NIL		0.231558964959666
2015	Polyline	ROAD	ACCEPT	ACCEPT	23	0.186065637491011
2020	Polyline	ROAD	NIL	NIL		0.182455766057888

Figure 5. 5: Instance of Add delta table for proposed underground utility feature classes

5.3.4 Version Manager

The first step in versioning is version creation; the last one is version deletion. Version creation is creating a newer version from the default geodatabase. In this study, to make changes on the default geodatabase, first we created a version of the default geodatabase. This helps the geodatabase can be edited by many authority editors concurrently. Java has a method to create a version of ArcSDE geodatabase. Every version geodatabase has a parent except the default geodatabase and every version geodatabase may have a child version. Every version has version state ID which is used to uniquely identify the version of a geodatabase, and version name which handle the name of the version. In our case the version we created has a name “UtilityGDVer1” and the parent of this version is default ArcSDE geodatabase. MUUMCA version manager component is implemented using java geotool ArcSDE API in order to create, modify and remove versions. Java geotool API has a method “*create* (arg1, arg2)” to create a newer version from previously existed version and has a method *delete*() to remove a version. The deleted version must be a leaf node and can't be a parent to another version. To create or delete a version, first the user needs to be connected with ArcSDE geodatabase. Java geotool API has a class SeConnection to easily connect ArcSDE geodatabase with java application. This class has parameters like server_name where the geodatabase is stored, instance or port number we gave when we connect the ArcSDE software development kit for oracle with oracle database management system, name of geodatabase or tablespace , user name and password of geodatabase administrator. Version creation is done from the DEFAULT geodatabase using SeVersion class which has two argument the first one is the object of the connection and the other is the name of parent geodatabase. The object of SeVersion has a “create()” method to

produce version from the existed one. The create method has two arguments need to pass the first argument has a boolean value in order set unique name for a version and object of SeVersion. You can require a unique name by setting boolean value to true. Even If the name isn't unique, the ArcSDE software will append some characters value to create a unique version name. If this flag is false and a version of this name already exists, then the version creation will fail.

5.3.5 Version Editor

In order to implement version editor component, we created an ArcSDE service which helps to convey spatial data between GIS applications and oracle database. The ArcSDE service is used to make multiple client connections to the database using giomgr ArcSDE service component. In our study, we have a geodatabase with the name “sde” and an ArcSDE service with the name “esri_sde.service”. The service has a port number of 5151, which is oracle default ArcSDE connection TCP/IP port number. Applications submit connection requests to the ArcSDE service and the giomgr process responds to connection requests serially. In order to serve the request application, the giomgr process starts a gsvr process which helps to connect the application with default ArcSDE geodatabase. After connection between application and geodatabase is built, another remaining task was registering a geodatabase feature data set as versioned. ArcCatalog software has a component Registered as versioned, which helps users to create multiple versions of the original geodatabase and a base to implement versioned spatial editing approach. In our study, a versioned feature dataset of the system consists of RoadFC, TelecomFC WaterFC and EEPC base table plus any changes in the feature class is stored delta tables. The geodatabase keeps track of which version you were connected to when you made the edits that populated the delta tables. When you query or display a dataset in a version, MUUMCA system assembles the relevant rows from the original table and the delta tables to present a seamless view of the data for that version. The two delta tables play a great role to implement MUUMCA version editing component. Add delta table used to store newly installed features of feature classes and contains version state ID of the version where the feature is edited, attributes to accept response of other authorities and feature objectID whereas the delete delta table used to store deleted features with same attributes as add delta table.

5.3.6 Topological Relationship Checker

There are different types of topological relationship of a layer like union, intersection, touches, and disjoint. Actually topological relationship checker basically is used to identify the relationship between different feature classes. In our study, we used topological relationship in order to determine which authority underground infrastructure will be affected by the newly installed infrastructure? The common topological relationship that exists between vector polyline feature classes is intersection. The intersection checker is used to test out which service provider is affected by the change; it might be adding of layer or removing of a layer. In order to implement topological relationship checker, we used java geotool library. Java has a geotool application program interface used to check the relation among feature classes. First the system creates the connection with ArcSDE geodatabase and retrieves all feature classes from geodatabase. When users are done with the change the newly created geometry accepted as SeShape object. Geotool SeShape class has isCrossing(), isOverlapping(), and isDisjoint() methods for checking relation among polyline feature classes. In our study, isCrossing geotool SeShape class method is used to implement topological relationship of MUUMCA. This method returns a boolean value true if there is an intersection between newly installed feature and other feature classes, else it returns false. As shown in Annex I, topological relationship among feature classes is implemented by using java “if else” conditional statements.

5.3.7 Transaction Manager

The kind of transaction we used in order to implement MUUMCA spatial data editing is long transaction. Long transaction is a transaction which can span over a long period of time. Hence, we need to control the transaction properly. To implement this long transaction, we basically used triggers and PL/SQL procedures. Oracle Database trigger invokes ("fires") automatically when certain events occur, for example, when a DML operation modifies a certain table like Adds and Deletes tables. The Add and Delete tables have attribute used to accept posts from other authorities. There are two basic types of triggers in oracle database management system: Row level trigger and statement level trigger as we described in (chapter two). The kind of trigger we used to manage the transaction of our system is update For Each Row Type row level trigger. The trigger will be fired after any update data manipulation operation is performed on three attributes of Add and Delete delta tables and helps PL/SQL procedures executed

automatically. In order to check replay messages of each authority oracle PL/SQL “if” conditional statement is used. MUUMCA system has an interface, which helps different authorities’ editors to post their replay message for a change that affects them. If all affected authority accepts the change, the change is committed to the original database else the change will be aborted as shown in Figure 5.6.

```

CREATE OR REPLACE TRIGGER ROAD_CHECK
AFTER UPDATE ON SDE.ADDS
FOR EACH ROW
DECLARE
    TRESP sde.adds.telecom_response%type;
    WRESP sde.adds.water_response%type;
    OOBJECTID sde.adds.objectid%type;
    SHP sde.adds.shape%type;
    IID sde.adds.id%type;
BEGIN
    TRESP := :new.TELECOM_RESPONSE;
    WRESP := :new.WATER_RESPONSE;
    OOBJECTID:= :new.OBJECTID;
    SHP:= :new.SHAPE;
    IID:= :new.ID;
IF (TRESP = 'ACCEPT' AND WRESP = 'ACCEPT') THEN
        {
            insert into SDE.ROADFC(OBJECTID,SHAPE,ID) values (OOBJECTID,SHP,IID);
        }
ELSIF((TRESP = 'REJECT' AND WRESP = 'ACCEPT') OR (TRESP = 'ACCEPT' AND WRESP =
'REJECT')
OR (TRESP = 'REJECT' AND WRESP = 'REJECT') ) THEN
        {
            delete from ADDS where OBJECTID=OOBJECTID;
        }
END IF;
END;

```

Figure 5. 6: Two phase commit protocol using trigger and PL/SQL procedure

5.3.8 Utility Mapper

The utility mapper component basically is designed to display or visualizes utilities maps in an attractive way. Nowadays there are many client mapping application programs used to display maps in away suitable for users. For our work, we used Openlayer client mapping software to visualize maps from geodatabase through web mapping server (WMS). Openlayer has a capability in order to access web map server layers using java script methods. First, we need to publish ArcSDE layer using web map server. To publish layers using WMS, first we need to

create a connection between Geoserver and ArcSDE geodatabase. After we created the connection, the layers those existed on the geodatabase will be displayed as ready to publish as a single ArcSDE workspace. Geoserver supports the two basic web map service version WMS 1.1 and the latest WMS 1.3. We used WMS 1.3 to publish layers in feature dataset of ArcSDE geodatabase. After we published the layers, openlayer JavaScript based client mapping application is used to visualize and assign a color coding system based on the color coding standard of American Wire Producers Association, to easily identify one utility map layer from another. In this study to represent map layers of each authority with unique color based on APWA, we created a Styled Layer Descriptor (sld) files as shown in Figure 5.7.

```

<?xml version="1.0" encoding="ISO-8859-1"?>
<StyledLayerDescriptor version="1.0.0"
xsi:schemaLocation="http://www.opengis.net/sld StyledLayerDescriptor.xsd"
xmlns="http://www.opengis.net/sld"
xmlns:ogc="http://www.opengis.net/ogc"
xmlns:xlink="http://www.w3.org/1999/xlink"
xmlns:xsi="http://www.w3.org/2001/XMLSchema-instance">
  <!-- a Named Layer is the basic building block of an SLD document -->
  <NamedLayer>
    <Name>Water_line</Name>
    <Title>Underground water pipeline</Title>
    <Abstract>A sample style that draws a line</Abstract>
    <FeatureTypeStyle>
      <Rule>
        <Name>rule1</Name>
        <Title>Blue Line</Title>
        <Abstract>A solid blue line with a 1 pixel width</Abstract>
        <LineSymbolizer>
          <Stroke>
            <CssParameter name="stroke">#0000CC</CssParameter>
            <CssParameter name="stroke-width">2</CssParameter>
          </Stroke>
        </LineSymbolizer>
      </Rule>
    </FeatureTypeStyle>
  </NamedLayer>
</StyledLayerDescriptor>

```

Figure 5. 7: Styled Layer Descriptor for water utility layer

Figure 5.7 shows styled layer descriptor (sld) file we created to represent AAWSA water utility layer using blue color and line width of 2 pixels. The remaining three utility service provider layers are represented by creating sld files with different color representation for each underground utility layers of a spatial dataset as a water utility layer. Telecom utility layer is

represented using orange color, road layer represented by gray, electric layer represented by red and we used pink color to represent proposed utility lines of any authority based on AWWA color coding system standard as we described in chapter two. This helps service provider editors easily identify the location of their underground infrastructures. Figure 5.8 shows transportation and underground utilities networks of Addis Ababa city service providers represented using the proposed utility color coding system.

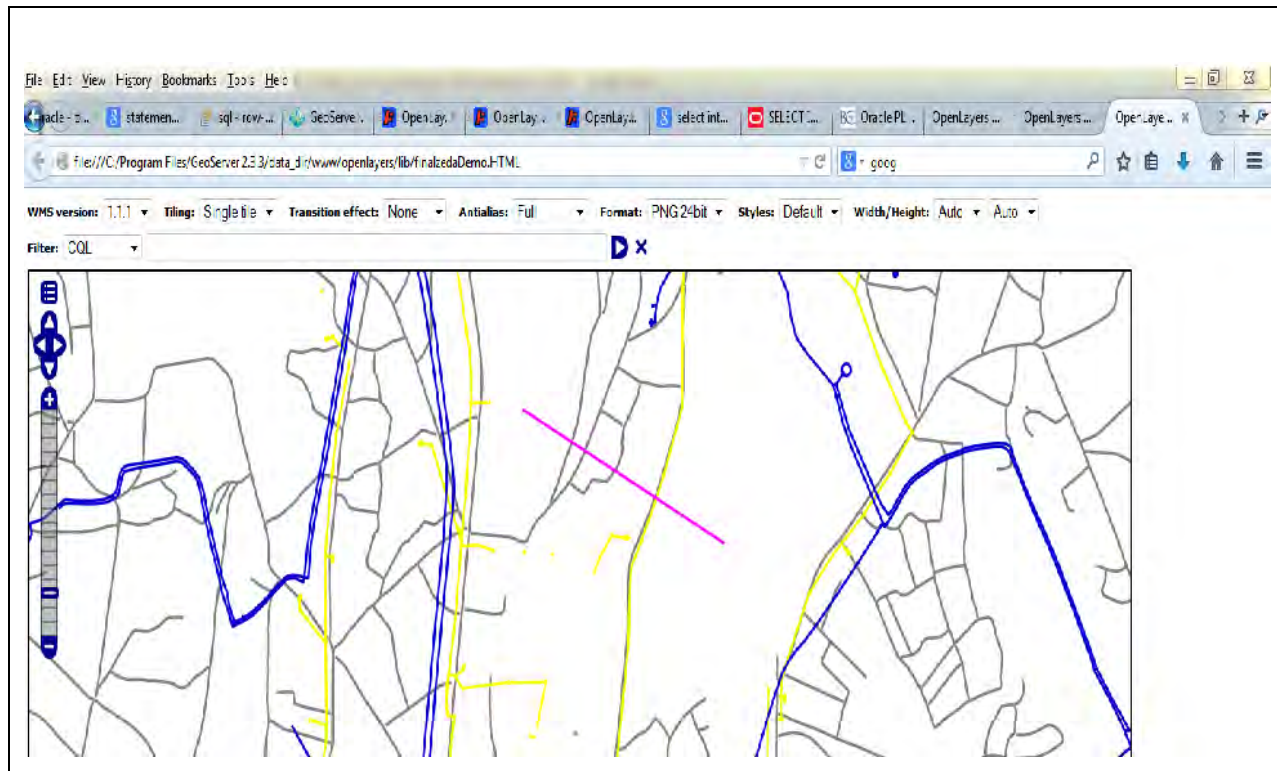


Figure 5. 8: Transportation and utilities network of AA city service providers

5.4 Testing Versioned Spatial Data Editing Workflow

The proposed versioned spatial editing workflow of GIS Centric Underground Utility Monitoring system underground utility spatial data editing was tested for the proof of concept for the purpose of supporting a business case for a statewide infrastructure and workflow change.

In this system, permissions were established on the four of the layers explained in the example described in Figure 5.1, namely telecom layer, water layer, electric layer and the road layer to emulate the four authorities that control these four layers, after versioning was initiated, for this proof of concept. Four separate editors were identified and named telecom editor, water editor,

electric editor and road editor. It was assumed that the road editor would be the one to make the changes and post them. Changes were then made to the road layer as described in the workflow earlier summarized in Figure 4.4 above. MUUMCA system has an interface to add a number of coordinate (longitude, latitude) data those we got from GPS survey of an area where we want to install road infrastructure as shown in Figure 5.9. From the points we inserted, the system draws a new vector line feature automatically. Upon completion of the changes, the data was made ready for posting. Installation of the road infrastructure affected all three authorities' infrastructures hence installation need accept post from all three authorities. Triggers were set up on the Add delta version states table to capture "post" request from the user. When a post request was initiated, it was routed as an event message to the telecom editor, water editor and the electric editor to simulate the "request post" step as shown in Figure 4.4.

Node/Point	Longitude	Latitude
Start node/point -1	473599.25	1000619.58
End node/point-3	473951.19	999682.47
Turn node/point-2	473567.69	1000253.29

Figure 5. 9: Utility spatial data editing

The telecom editor, water editor and the electric editor were each asked to review their respective layer and post, which again created notification to the road editor. The telecom, water, and electric editor only reviewed their spatial data layers and initiated a post. The system has an interface to vote for accept or reject spatial data changes of a specific line feature.

A small java web based utility is created to actually commit the four transactions into the default geodatabase. When post message has been received from all of the three editors, the utility does the process of posting. ArcSDE uses the sde_state_id to keep track of the version. The correct

SDE_state_id was identified for the version edited. The utility then identifies the changes in add and delete tables where changes made in the version are recorded. A modify feature is recorded both as a delete in the delete table, followed by add in the add table. A snapshot of the add table showing the changes is summarized in Figure 5.5.

5.5 Evaluation of the system

5.5.1 Evaluation of Utility Base Map Accuracy

The success of a GIS system depends on the accuracy and quality of the obtained spatial data required for development of the GIS system [58]. Spatial data quality is the degree of data excellence that satisfies the given objective. Spatial data we got from four utility service provider authorities had discrepancies in terms of format, projection, map scale, extent and had lots of digitization errors like topological errors. Spatial data quality is a pillar in any GIS implementation and application as reliable data are indispensable to allow the user obtaining meaningful results. In this study to have quality underground utility spatial information, we have done a lot of quality improvement methods in different stage of entire MUUMCA system development. The first spatial data quality improvement we have done was enhancement on the accuracy and precision of spatial data that we acquired from GPS survey. In addition to the GPS devices accuracy, we have done different techniques like surveying ground control points many times with good atmospheric condition and took average ground control point for a specific area to aid the MUUMCA system to have more accurate and precise spatial data results. The other improvement we have done on underground utility spatial data quality was, preprocessing of service providers underground utilities spatial data such as projection, topological error correction and coordinate transformation to increase positional accuracy of underground utility map.

In this study, the horizontal positional accuracy of service providers' underground utility map is evaluated using a Root Mean Square Error statistical formula. To evaluate the utilities map accuracy we took latitude and longitude data of a well defined objects like monuments, road intersection, and utility manholes both on the map and on the ground.

Table 5. 4: Evaluation of utility map accuracy

No	Service provider	Ground control points		Map reference points		Average RMSE(meter)
1	Road	473777.59	999664.74	473778.91	999662.45	2 meters
		473452.18	999831.02	473452.59	999831.02	
		473628.62	999751.13	473626.41	999750.29	
		473991.78	9984927.21	473990.62	9984925.05	
2	Water	473855.63	998319.99	473853.39	998317.94	3 meters
		474005.78	997409.70	474003.18	997411.74	
		472554.39	998029.77	472556.29	998028.17	
		472696.60	998799.14	472693.30	998800.11	
3	Electric	471798.65	998444.27	471796.73	998442.32	3 meters
		473247.28	997774.83	473248.18	997775.53	
		471804.07	998449.63	471803.07	998448.63	
		474410.01	997999.80	474410.01	997999.80	
4	Telecom	473777.59	999665.74	473776.15	999667.25	4 meters
		473753.50	999704.01	473755.21	999708.74	
		473991.34	998492.89	473995.47	998490.32	
		473798.22	999681.49	473796.65	999678.12	

From the results we have shown in Table 5.4, the accuracy of utility map layers in ArcSDE geodatabase using test points are telecom layer has accuracy up to 4 meters, electric utility layer to 3 meters, water utility layer to 3 meters and road layer to 2 meters. The average spatial accuracy of MUUMCA ArcSDE geodatabase feature dataset is less than 3 meters. From positional map accuracy results we have got from experiment, it is possible to deduced that the proposed work and its implementation is usable to provide utility services, to co-edit maps and authenticate utility maintenance services.

5.5.2 Evaluation of the System by Utility Service Providers

GIS based underground utility map co-editing and authentication system evaluation is the process of determining the quality of the proposed system and the spatial information it provides. It is important for any software development effort to ensure correctness of the outputs and user satisfaction with the product in solving the given problem.

In order to evaluate the proposed system, we used some common criteria such as usability, impact of integrating utility maps, impacts of quality of the utility map information and usefulness of the system. Based on these criteria we prepared questionnaires (see Annex: III).

Two ethio telecom, two water authority, two Ethiopian Road Authority and two Ethiopian electric power corporation workers a total of eight who are technically fit respondents from each service providers were selected and participated in the evaluation process. The respondents are provided with the system evaluation questionnaires. In the questionnaires, users are required to evaluate the system using ordinal scale from strongly disagree (rating 1) to strongly agree (rating 5). Table 5.5 gives the result of the evaluation.

Table 5. 5: Result of User Evaluation

	Strongly agree	Agree	Neutral	Disagree	Strongly disagree	
Q No	(5)	(4)	(3)	(2)	(1)	Average (%)
1	4	3	1	0	0	87.5
2	3	4	1	0	0	85
3	5	3	0	0	0	92.5
4	4	3	1	0	0	87.5
5	6	1	1	0	0	92.5
6	3	4	1	0	0	85
7	3	4	1	0	0	85
8	3	3	0	2	0	77.5
9	5	2	0	1	0	87.5
10	4	4	0	0	0	90
11	3	4	1	0	0	85
12	4	3	0	1	0	85
Overall Average						86.6

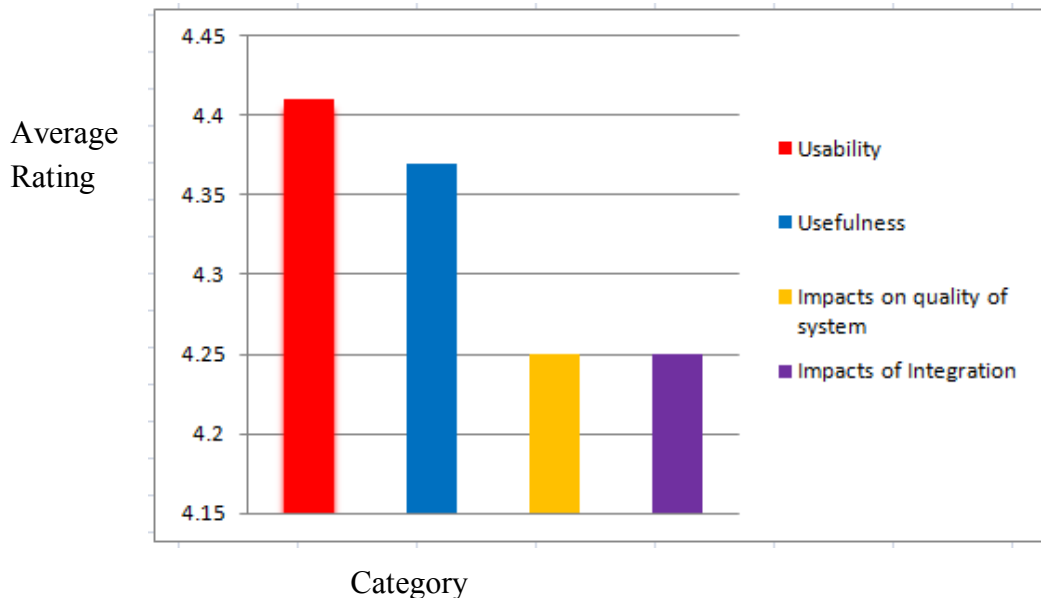


Figure 5. 10: Evaluation Result based on User Rating

From the result analysis as shown in Figure 5.10, it can be concluded that the respondents agreed that the system satisfies the following criteria: usability, impact of integrating utility maps to resolve problems on underground infrastructure, impacts of quality of the utility map spatial information and usefulness. On the average, the performance of the proposed GIS based multi-user underground utility map co-editing and authentication system is 86.6%. Hence, the proposed system is rated acceptable in order to manage geospatial information of service providers underground infrastructure and useful to reduce maintenance costs.

Chapter Six: Conclusion and Future Work

6.1 Conclusion

Government agencies are in desperate need of using technology to plan, maintain, and manage their utility spatial data. GIS has played vital role in the expansion and maintenance of the public utilities spatial data that are available in different types, formats, locations, sizes management and development plans. However, since several utility service providers have difficulty of sharing utility maps on the common land resource, co-editing and authentication has always been a problem.

This work has presented a versioned based underground utility spatial data editing and authentication system for underground utility service providers. The versioned based approach, as discussed in Chapter Two, is an approach which can be used for editing map by creating a version of the original geodatabase which used to support concurrent multi-agent spatial data editing.

The developed GIS based Multi-user Underground Utility Map Co-editing and Authentication system has different components. The spatial data acquisition component is used to acquire underground utility spatial data from service providers. The acquired utility spatial data is supplied to spatial data preprocessor component. The spatial data preprocessor component is used to correct utilities map format, scale and extent, smooth topological errors and transform coordinates of utilities to same coordinate system. The preprocessed utility spatial data is stored in ArcSDE geodatabase. To test the applicability of utilities spatial data editing using versioning approach, the system first creates a version of the original geodatabase and an editor perform editing by using version editor component. The topological relationship analyzer component is used to check whether the proposed utility line affect other service provider or not. Then, the request and accept post messages of each affected service providers response message is managed by trigger and PL/SQL components and the change is done on the original geodatabase using the version poster component.

Lastly, the implementation of the proposed model is evaluated using the data of four utility service providers in Addis Ababa. The underground utility map accuracy of service providers in Addis Ababa is evaluated using Root Mean Square Error metric. Finally, the proposed system is

evaluated by eight different service providers’ workers and we got an average system performance of 86.6%. From this result, we conclude that the integrated underground utility map editing and authentication system is vital to manage underground infrastructure spatial data and helps to identify the location of underground utility easily and highly supports to protect service providers’ underground infrastructure from damage.

6.2 Contribution of the Work

Among the major contributions of this thesis are:

- Identifying and proposing the procedures, techniques, algorithms and tools used for the development of public utilities spatial data management system.
- Proposed a new model for Multi-user Underground Utility Map Co-editing and Authentication system with the state of the art approach.
- Proposing a color coding system for easily representing underground utilities map layer using different colors.
- Design of a system that enables public utility service providers to have up to date underground utilities spatial information.
- GIS based system used to control and supervise unauthorized excavation of underground infrastructures which basically helps to protect infrastructure from damage.

6.3. Future Work

The proposed utility spatial data editing model could be extended further in three ways.

- Identification of underground utility leakage by using sensors and the issues and ways to remedy would have to be explored.
- A trust model needs to be investigated that would minimize the number of “accept post” requests that would have to be initiated and hence the overall delivery cycle time. However, the implications of this would have to be further studied.
- This system is at thesis level then other researcher can develop a full-fledged underground utilities spatial data editing and identify a way to design utility maps of medium or small size underground infrastructures including the customer line.

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ANNEXES

I. Sample code segments

Sample code to Create version of original geodatabase

```
public class CreateVersion
{
    static SeConnection conn = null;

    static String server    = "zeru-PC";

    static String instance  = "5151";

    static String database  = "sde";

    static String user      = "sde";

    static String password  = "toti";

    public static void main(String args[])
    {
        try
        {
            conn = new SeConnection(server, instance, database,user,password);

            SeVersion ver = new SeVersion(conn,"DEFAULT");

            ver.setName("UtilityGDVer1");

            ver.create(true, ver); }

        catch(Exception exxx)

        {
            System.out.println(exxx.getMessage());
        }
    }
}
```

Sample code to edit ArcSDE map layer

```
public class LayerEditing
{
    static SeShape shp1,shp2,shp3;

    static SeLayer layer = null;

    private static SeConnection conn = null;

    static int i=0;

    public static void main(String[] args)
    {
        SeGeometry g;

        String server    = "zeru-PC";

        String instance  = "5151";

        String database  = "sde";

        String user      = "sde";

        String password  = "toti";

        SgShape v;

        //SeShapeFilter.

        try {

            System.out.println("Connecting to the ArcSDE Server...");

            conn = new SeConnection( server, instance, database, user, password );

            Vector layerList = conn.getLayers();
```

```

//SgShape gh=(SgShape)layerList.firstelement();

SeLayer theLayer = (SeLayer)

layerList.lastelement();//elementAt(3);//elementAt(0);

// SeGeometry gggg=(SeGeometry)layerList.firstelement();

System.out.println(" - Done."+theLayer.getName());

//tyu= (SeShape)layerList.elementAt(1);//firstelement();

//tyu2= (SeShape)layerList.elementAt(2);

//SeShape tyu= (SeShape)layerList.elementAt(3);

//tyu3= (SeShape)layerList.lastelement();//firstelement();

System.out.println(" - Done.");

insertData(theLayer);

System.out.println("Disconnecting from server... \n");

conn.close();

}

catch( Exception e ) {

    e.printStackTrace(); }

}

public static void insertData(SeLayer layer) throws SeGeometryException

{

String columns[] = new String[2];

//columns[0] = new String("OBJECTID"); // Integer column

```

```

columns[0] = new String("ID"); // Shape column

columns[1] = new String("SHAPE");

SeInsert insert = null;

try
{
    insert = new SeInsert(conn);

    insert.intoTable(layer.getTableName(), columns);

    insert.setWriteMode(true);

    SeRow row = insert.getRowToSet();

    SeCoordinateReference coordref = layer.getCoordRef();

    // System.out.print(""+coordref);

    int numParts = 1;

    int partOffsets[];

    partOffsets = new int[numParts];

    partOffsets[0] = 5;

    SeShape point = null;

    point = new SeShape(coordref);

    int numPts = 2;

    SDEPoint[] ptArray ;

    ptArray = new SDEPoint[numPts];

    ptArray[0] = new SDEPoint(474045 ,1001035);

    ptArray[1] = new SDEPoint(474622 ,1000762);

```

```

point.generateLine(numPts, numParts, partOffsets, ptArray);//generatePoint(numPts, ptArray);

    row.setInteger(0, 23);

    row.setShape(1, point);

    // insert row

    insert.execute();

    System.out.println("\tinserted row ");}

catch (SQLException e)

    { e.printStackTrace();

    }

} // End method insertData

```

Sample code to check topological relationship

```

if(point.isCrossing(tyu))
{
    System.out.println ("line intersect road layer");
}
else if(point.isCrossing(tyu3))
{
    System.out.println ("line intersect water layer");
}

```

```

else if(point.isCrossing(tyu2))
    {
        System.out.println ("line intersect telecom layer");
    }
else
    { System.out.println ("line does not intersect telecom layer");
    }

```

Sample code for displaying a utility map layer

```

<!-- Import OpenLayers, reduced, wms read only version -->

<script src="http://localhost:8083/geoserver/openlayers/OpenLayers.js" type="text/javascript">

</script>

<script defer="defer" type="text/javascript">

    var map;

    var untiled,untiled2;

    var tiled,tiled2;

    var pureCoverage = false;

    // pink tile avoidance

    OpenLayers.IMAGE_RELOAD_ATTEMPTS = 5;

    // make OL compute scale according to WMS spec

    OpenLayers.DOTS_PER_INCH = 25.4 / 0.28;

    function init(){

        var bounds = new OpenLayers.Bounds(

```

```

472367.4078, 997039.2718,
476123.0686, 1002408.8651
);

var options = {

controls: [],

maxExtent: bounds,

maxResolution: 20.974973828125258,

projection: "EPSG:20137",

units: 'm'

};

map = new OpenLayers.Map('map', options);

// setup tiled layer

tiled = new OpenLayers.Layer.WMS(

"sde:SDE.ROADFC - Tiled", "http://localhost:8083/geoserver/sde/wms",

{

LAYERS: 'sde:SDE.ROADFC',

STYLES: 'EtRoad_line',

format: format,

transparent: 'true',

tiled: true,

tilesOrigin : map.maxExtent.left + ',' + map.maxExtent.bottom

```

```
},  
  
{  
  
  buffer: 0,  
  
  displayOutsideMaxExtent: true,  
  
  isBaseLayer: true,  
  
  yx : {'EPSG:20137' : false}  
  
});
```

```
tilled2 = new OpenLayers.Layer.WMS(  
  
  "sde:SDE.ADDS - Tiled", "http://localhost:8083/geoserver/sde/wms",  
  
  {  
  
    LAYERS: 'sde:SDE.ADDS',  
  
    STYLES: 'ppp',  
  
    format: format,  
  
    transparent: 'true',  
  
    tiled: true,  
  
    tilesOrigin : map.maxExtent.left + ',' + map.maxExtent.bottom  
  
  },  
  
  {  
  
    buffer: 0,  
  
    displayOutsideMaxExtent: true,
```

```

        isBaseLayer: false,

        yx : {'EPSG:20137' : false}

    });

// setup single tiled layer

    untiled = new OpenLayers.Layer.WMS("sde:SDE.TELECOMCOMFC - Untiled",
    "http://localhost:8083/geoserver/sde/wms",

        {

            LAYERS: 'sde:SDE.TELECOMCOMFC',

            STYLES: 'Telecom_line',

            transparent: 'true',

            format: format

        },

        {

            singleTile: false,

            ratio: 1,

            isBaseLayer: false,

            yx : {'EPSG:20137' : false}

        }

    );

```

```
untiled2 = new OpenLayers.Layer.WMS("sde:SDE.WATERFC - Untiled",  
"http://localhost:8083/geoserver/sde/wms",
```

```
{  
  
  LAYERS: 'sde:SDE.WATERFC',  
  
  STYLES: 'Water_line',  
  
  transparent: 'true',  
  
  format: format  
  
},
```

```
{  
  
  singleTile: false,  
  
  ratio: 1,  
  
  isBaseLayer: false,  
  
  yx : {'EPSG:20137' : false}  
  
}
```

```
);
```

```
map.addLayers([untiled,untiled2,tiled,tiled2]);
```

```
// build up all controls
```

```
map.addControl(new OpenLayers.Control.PanZoomBar({
```

```
  position: new OpenLayers.Pixel(2, 15)
```


III. System evaluation Questionnaire

GIS based multi-user underground utility map co-editing and authentication System evaluation Questionnaire

Objective:

This survey is conducted to gather data on the evaluation of GIS based underground utility map co-editing and authentication.

Instruction: Choose and circle the most appropriate score for each question given below.

Score	
Strongly Disagree	1
Disagree	2
Neutral	3
Agree	4
Strongly Agree	5

			Rating Scales				
	No	Evaluation Questions	1	2	3	4	5
Usability	1	The system is easy to learn and understand					
	2	The system is user friendly					
	3	The system represents your authority underground infrastructure map using recommended color					
Usefulness	4	The system helps your authority to manage underground utility spatial information					
	5	The system is vital to identify the location of your authority underground infrastructure easily					
	6	The system is useful to determine distribution of infrastructure to the society easily					
	7	The system is secured; unauthorized user can't make a change					
Impact on quality of system	8	The system is accurate to locate underground infrastructure					
	9	The system georeferenced underground utility map accurately with the proper coordinate system					
	10	The system resolves your authority underground utility map topological errors properly					
	11	The system has a quick response time					
Impact on integration	12	Integrating your authority utility map with others helps to protect infrastructure from damage; this will reduce maintenance cost and help to provide services properly					

DECLARATION

I, the undersigned, declare that this research is my original work and has not been presented for degree in any other university, and that all sources of materials used for the research have been acknowledged.

Declared by:

Name: Zerihun Mulugeta

Signature: _____

Date: _____

Confirmed by advisor:

Name: Solomon Atnafu (PhD)

Signature: _____

Date: _____

Place and date of submission: Addis Ababa University, March 2015.