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Research Article

GIS Web Services for Road Management System in Tigrai, Mekelle

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ABSTRACT

The development of road transport is one of the key features to an overall better standard of living; it is currently the heart of regional connectivity for the continents of Africa. Road management covers the activities of planning, designing, implementing, and decision makings for road development programs. In Tigrai, Ethiopia, road management is still managed in a poorly organized way, leading to data slow decision making processes. There are issues of data redundancy, inconsistency and incompleteness, no use of spatial technologies for spatial information as such, long processing time and inaccurate information is implemented. The objective of this study was to explore the role of new and emerging Geographic information System (GIS) technologies, explicitly Service Oriented Architecture (SOA) web services for road management and thereby supports the planning and management functions of the The research started by assessing the status of current road management and planning activities using questionnaires, interviews, observation and consulting existing documents. The study then reviewed the current trends of SOA web services for effective road management and planning. System design which includes use case, activity diagrams were modeled using Unified Modeling Language (UML) and creation of shape files for map files were done. Next, the SOA web service prototype was developed using map server with p-mapper scripts. Various queries using map server scripts were developed and tested. Results were used as a baseline in order to develop the system that can be implemented in reality. This study showed how such a system can be developed with low-cost available technologies. The method can be adopted to develop road management and planning in other cities of the country. The prototype is simple to use and facilitates searching roads' information in space and time supported by interactive analytical tools.

Keywords: Web Services; Service Oriented Architecture (SOA); MeRA

INTRODUCTION

Currently roads are the heart of regional connectivity for the continent especially in Africa. Roads are major components of urban infrastructures that constitute the main infrastructure serving to regional connectivity, carrying majority goods and passengers in day to day activities. However, it is characterized by missing links and poor road maintenance managements [1].

Web services in road management is an important tool to get the accurate information from relevant bodies in space and time. This information can be used as a guidance for decision makers to make decisions as it is used as spatial decision support systems (SDSS). SOA web services provides an integrated system for spatial and non-spatial roads' information in order to retrieve, select, query and generate reports of road information on web [2, 3]. Web services with the provided by the GIS, merges for a model for visualization, management, and analysis of geographic information, as a valid and effective tool for public administrators to aid in decision making in management and planning of the regional entity[4].

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In this study, the researcher has envisioned to underline SOA web services that will serve as a platform for road management and planning in Mekelle Road Authority. The current Road management and planning system in Mekelle, it is lacking the required functionalities of a modern road management and planning system; data requirement definitions, data collection methods, data organization and storage mechanism, software platform, data analysis techniques, data update and maintenance, data production techniques, data searching techniques, standards and data exchange as well as data access techniques. SOA comprises a flexible set of design principles used during the phases of system development and integration. The deployment of a SOA based architecture will provide a loosely integrated suite of services that can be used within multiple areas of domains. The enabling technologies in SOA allows services to be discovered, composed, and executed. For instance, when an end-user wishes to accomplish a certain task, a service can be employed to discover the required resources for the task. This will be followed by a composition service which will plan the road-map to provide the desired functionality and quality of service to the end-users [5, 6].

Architecture of Service Oriented Architecture (SOA)

SOA approach applies within the GIS domain where several standards have been launched. This technology moves from standalone GIS applications towards a more loosely coupled and distributed model based on self-contained, specialized, and interoperable geospatial web services. In order to create SOA architecture for the GIS services it is necessary to create web service correspondences of each GIS services. GIS services can be grouped into three categories- data services, processing services and registry services [7].

Data Services- are tightly coupled with specific data sets and offer access to customized portions of that data. Web Feature Service (WFS), Web Feature Service-Transactional (WFS-T), Web Mapping Service (WMS) and Web Coverage Service (WCS) can be considered in this group. WMS produces maps as two-dimensional visual portrayals of geospatial data. WCS provides access to un-rendered geospatial information (raster data). WFS provides geospatial feature data (vector data) encoded in Geography Markup Language (GML) whereas WFS-T enables editing feature coordinate geometry (i.e. position and shape) and related descriptive information (i.e. attribute values), as well.

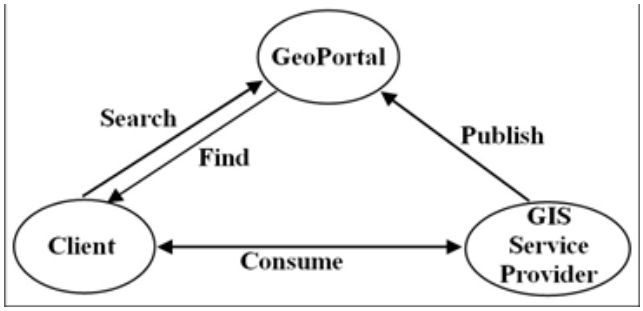
Processing Services- provide operations for processing or transforming data in a manner determined by user-specific parameters. They provide generic processing functions such as projection and coordinate conversion, rasterization and vectorization. Coverage Portrayal Service (CPS) and Coordinate Transformation Service (CTS) can be considered in this group.

Registry or Catalog Service- allows users and applications to classify, register, describe, search, maintain, and access information about Web Services. Web Registry Service (WRS) and Catalog Service for the Web (CS-W) are considered in this group.

Service Orientation is the result of the natural evolution of current development models such as structural, object oriented and component based methods. Object-oriented models were used in the 1980s; and then they were replaced by the component-based development models in the 1990s. And now we have service orientation. Service orientation retains the benefits of component-based development (self-description, encapsulation, dynamic discovery and loading), but there is a shift in paradigm from remotely invoking methods on objects, to passing messages between services [8].

Service Oriented Architecture is an architecture used in software development based on the concept of Service. A service can be defined as an independent function which is well defined and self-contained. In SOA, different services communicate with each other to perform some activity. SOA is a very popular architecture paradigm for designing and developing distributed systems. SOA solutions have been created to satisfy business goals that include easy and flexible integration with legacy systems, streamlined business processes, reduced costs, innovative service to customers, and agile adaptation and reaction to opportunities and competitive threats of SOA. A service is a unit of work done by a service provider to achieve desired end results for a service consumer. Both provider and consumer are roles played by software agents on behalf of their owners. The key component in the SOA is services. A service is well defined set of actions. It is self-contained, stateless, and does not depend on the state of other services [8-11].

Figure 1: The Basic Components & Operations of SOA.



SOA concept has three components (Fig.1): service provider, service registry, service requester and three operations: publish, find, and bind. A SOA relates the roles of the three components with the three operations to maintain automated discovery and the use of services. The three essential components mentioned above can be described as:

Service provider (server) - publishes services to a registry and makes it available on the Internet for the requests of the consumers.

Service requester (client) - performs service discovery operations on the service registry in order to find the needed service; then accesses services.

Service registry (broker) - helps service providers and service requesters to find each other by acting as a registry of the services.

Web Services: are functional components or application programming interface that can be accessed through internet

and SOA can be implemented at many different network environments. The implementation of SOA in web environment is called Web Services. The concept of Web services is based on service oriented architecture paradigm where a complete application can be constructed from various services which provide different functionalities. Web services are designed to be published as far as possible like web sites. Web services are self-contained, self-describing, modular new raise of web applications that can be published, located, and dynamically invoked across the web.

Simple Object Access Protocol (SOAP) - Messaging protocol - is responsible for encoding messages in a common XML format so that they can be understood at either end of a network connection. Simple Object Access Protocol (SOAP) is the specific format for exchanging Web services data over HTTP.

Web Service Description Language (WSDL) - Description Protocol- it is an XML format used for describing the public interface to a specific web service. Web Service Definition Language(WSDL) is used to describe what type of message a web service accepts and generates. It gives the answers to the questions who? What? Where? Why? How? When?

Universal Description Discovery and Integration (UDDI) – Discovery protocol- is the core and open registry standard for web services or centralizes services into a common registry. UDDI specification can be used by the service providers to advertise the existence of their services and by requesters to search and discover already registered services.

HyperText Transfer Protocol (HTTP) – Transport Protocol- is responsible for transporting messages between network applications. HTTP is the low-level protocol used by the Internet for the transport layer.

SOA web services can facilitate the road management system activities, which optimizes performance functionality, performance measurement, management costs, information flow, interoperability and reusability, organizational flexibility, software development, data confidentiality and integrity, reliability and ability to develop new functions rapidly [12].

Road management system in Mekelle activities comprise planning, designing, constructing, maintenance and other road related issues. Mekelle Road Authority is responsible to perform these activities. The activities of the Authority is lacking of searching road information in space and time. Hence, we aimed to design and develop SOA web services that will serve as a platform for road management and planning in Mekelle Road Authority.

Road Management in Mekelle Road Authority(MeRA)

As mentioned, in the above section, data and information in Mekelle road management, and activities are scattered in different departments and sections. There is no efficiently maintained data management system that supports road management and planning activities. Problems arise when planners of roads want to access and possibly query roads information. The first problem is that the spatial data related to road management is incomplete and not well maintained in database system so; it is difficult to get reliable roads information. The second problem is that it is difficult to access roads' information such as type and status of roads in space and time as the maps are static. The third problem is that static maps cannot be interacted with; planners cannot change the scale of a map; select an area of interest, identify sever roads, etc. Due to these problems, activities are not organized and prioritized to serve systematically. As shown in the Fig. 2, we collected through field survey in Mekelle, there are many damaged asphalt and cobblestone roads which needs immediate maintenance but the Mekelle Road Authority takes long processing time to make road planning and management decisions.

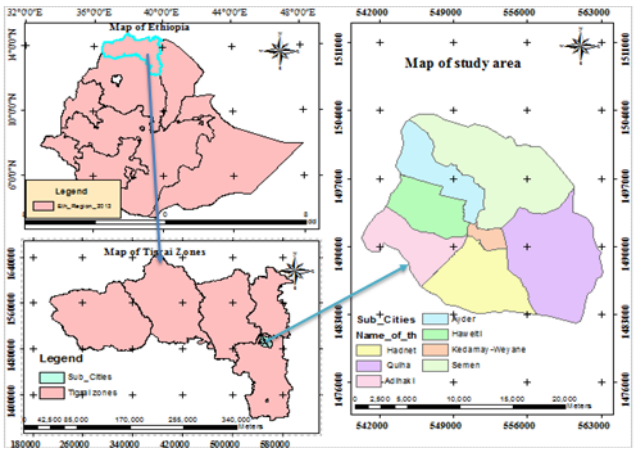
Figure 2: Damaged asphalt roads in Mekelle main road (Field work 2020).

Some of the key management questions are to search roads constructed at a particular time, to search specific type of roads, searching damaged roads for maintenance, identifying the status of roads, length of roads, year of construction, and to update road information etc. As such, the current system is not supported by web services and this negatively affects the activities of relevant authorities.

Description of study area

Mekelle was established in 1872 E.C when Yohannes IV ruled his empire. Currently the is the seat of the regional government of Tigrai. Mekelle is located at about 783 km. North of Addis Ababa on the main highway that continues Northward through Adigrat and Axum and it occupies an area of 100 sq. km. The City is located 390 28' East and 13032' North coordinates. Its altitude ranges from 2150-2300 m.a.s.l, which belongs to Dega (Medium high land) climatic zone. The average temperature of Mekelle is 19oc.

Figure 3: Map of the study area.



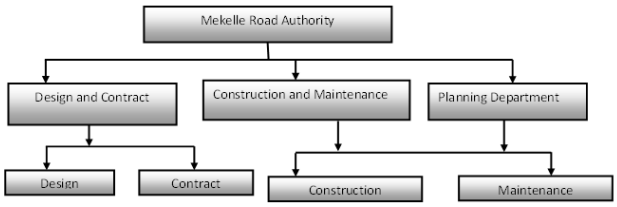
MATERIALS AND METHODS

This section has two parts. The first section is the assessment of road management system in Mekelle. Here target populations, sample and sampling techniques, data collection methods and data analysis method were included. The second section is focused on design, development and implantation of GIS web services.

Assessment of road management

Target population: The target population for this study was the community of Mekelle Road Authority and top managers and technical workers of Mekelle Road Authority were the participants for the study (Fig.4).

Figure 4: Departments and Sections of Mekelle Road Authority.



Sampling and sample determination: Purposive sampling method was used to collect the required information because the overall purpose of sampling was designed to generate a sample that will address research questions and the sample size was typically small thirty [13]. Questionnaires were distributed to a total of 24 participants; nine (9) in Constructions & Maintenance, seven (7) in Design & Contract and eight (8) in Planning Departments. Another questionnaire was distributed to three (3) top managers of each department.

Data collection techniques

Primary data sources: Primary data were gathered through questionnaires, interviews and observation. Questionnaires were distributed to the Departments of Constructions and Maintenance, Design and Contract, Planning Departments and top managers of each department. Interviews were conducted with the three top managers of each department formally and with some data managers/technical workers in each Department informally to support the result of questionnaires.

Secondary data sources: The secondary data were collected through the existing documents. Besides, the existing system was observed information about the current practice, data management and retrieval or data searching systems. Existing and accessible documents were also consulted: such as repots, action plans, posters and static map. The most recent shape files of roads from Mekelle Municipality were obtained.

Data analysis methods: According to the plan, data were collected through data gathering methods listed in the above and 92.67 % of the total participants in all departments of data managers except Planning Department responded complete answers. In the Planning Department participants answered only six questions from eight; total of twenty two participants of the data managers responded with complete answers. And three participants of the top managers responded appropriate answers. The collected data is analyzed and interpreted in tables, charts and percentages using MS Excel software.

Design and Implementation

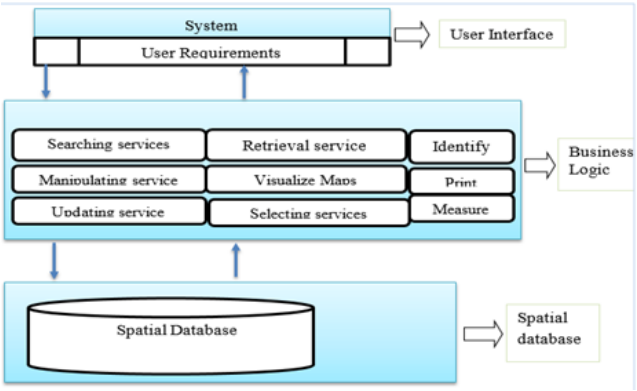
Design procedures :First, assess and identify appropriate data for roads from the current Road Management and planning system of Mekelle Road Authority was performed. Data and Information acquisition was conducted through questionnaires, interviews or investigation of existing documents and observations. This helped to identify the status of the existing system and needs and requirements for the new system to be developed. Next, the effectiveness of a SOA approach for such a purpose was investigated by using literatures review. More specifically, the focus was put on understanding how SOA approach can be used for effective road management and planning in terms of information searching, updating, visualizing. After that, a design of use case diagrams and activity diagrams using UML was created. A use cases diagram was used to the show the essential requirements for the new services. The use case is elaborated based on the activity diagram to show the service interaction as a result conceptual schema was developed [14-17]. Moreover, creation of geodatabase (shape-files) preprocessing and digitization via QGIS 2.18 tools was done.

Development and implementation: Based on the design of web service above, we develop a graphical user interface prototype to show how interactive analytical tools of web services facilitate the processing activities of road management and planning in Mekelle Road Authority. A user interface using open sources tools was developed accordingly. We implemented the prototype and checked the query testing for roads information such as searching asphalt roads where it status is sever, searching cobblestone roads constructed in 2018.

Functional Requirement: Determining user requirements is one of the basic and fundamental components of GIS design for each development and each user. The potential targeted users of this SOA web services for Mekelle road management and planning in Mekelle Road Authority including data managers, top managers and infrastructure management developers (IT groups), from Mekelle Municipality, Regional Head Office. Various academic and governmental agencies can also be granted access to the services. The required functions are: the service allows visualization the roadmaps: 1) A service allows searching specific data 2) A system that allows retrieving of specific information based on some criteria, 3) A web service allows selecting, measuring and identifying data.

System Components and Architecture: The Mekelle Road Authority (MeRA) has several components to accomplish its main aims using SOA Web services efficiently. These components are: searching services, manipulating service, retrieval service, selecting services, and querying, printing and measuring services. The general architecture of the service is based on the SOA approach.

Figure 5: System Architecture with its components.



User interface- allows and controls user system interaction. The recommendation service obtains information about users' need via SOA Web services user interface.

Business process- is the main component of the system which controls the overall interaction to provide analytical tools using Service oriented Architecture (SOA) approach in order to facilitate Road Management and planning activities. It comprises different services such as searching, retrieval services or spatial queries, map services and updating services.

Spatial Database- is the data model recommendation system which store users' information and spatial road data in a structured form. It allows automatic and active retrieval, updating and visualization of road data to support the infrastructure managements.

User Interface in Mekelle Road Authority for Management and Planning

The actual implementation process of the prototype was presented based on the designed geodatabase and user requirements listed above (Fig.5). The University of Minnesota's Map Server is an open-source and freely available map rendering engine for the web services. Due to its open-source nature, it can be compiled on a wide variety of platforms and operating systems. Map server is using Fast CGI via Apache/mod_fcgi. This is a CGI executable, meant to be called and run by your web server. Map-Server is a popular Open Source project whose purpose is to display dynamic spatial maps over the Internet. In its most basic form of Map Server is a CGI program that sits inactive on your Web server. When a request is sent to Map Server, it uses information passed in the request URL and the Map file to create an image of the requested map. The request may also return images for legends, scale bars, reference maps, and values passed as CGI variables. The user interface for Mekelle road management and planning was developed using Map Server. P-mapper framework was used to implement the system because of the providing the above functionalities [18, 19].

Basic Queries for Mekelle Road Management and Planning in MeRA

There are basic queries we constructed based on the demands of Mekelle Road Authority. The researcher also discussed about these queries with some data managers or technical workers of the office. Some of the basic questions that answered by the new developed prototype includes:

Where is the greatest sever of asphalt roads in Mekelle sub city?

What is the name of a road with a given street cod?

What is the length of the road with a certain starting and ending points of the roads?

Where are cobblestone roads where its status is good?

Which roads are constructed in a certain functional year?

RESULTS AND DISCUSSION

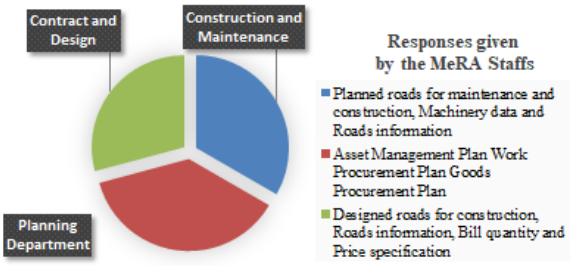
Assessment Results and discussion

This section is principally categorized based on the predefined research objectives and questions. The important findings are directly linked to the problem of road management and planning in Mekelle Road Authority. Data were collected, analyzed and interpreted.

Type of data or information handled in Mekelle Road Authority

Responses of all Departments or Sections of Mekelle Road Authority (MeRA) the data and information handled in their office. Q1. What type of available data at MeRA office?

Figure 6: Responses given by staffs for the data kept in MeRA office.



Majority (88.9%) of the total respondents from Construction and Maintenance Department answered that the data or information their office comprises planned roads for maintenance, planned roads for construction, and machinery data as well as inventory roads for maintenance. All the total participants from the Planning Department responded that the data or information handled in the Office consists asset management plan, work procurement plan and goods procurement plan. Majority (75%) of the respondents from Contract and Design Department answered that the data or information conveyed in the Office of Mekelle Road Authority contains designed roads for construction, roads' information, and bill quantity and price specification (Fig. 6).

Therefore, the findings explore that the data or information handled in Mekelle Road Authority are existing roads in terms of their road types, road status, street-codes, road names, and road length; planned roads for contraction; and planned roads for maintenance.

Software used in Mekelle Road Authority (MeRA) for management and planning

The Departments of the MeRA including top level managers responded for the software used for handling or storing their activities in their office.

Table 3: Data handling mechanism for road management and planning.

No	Question	Responses	
		Yes	No
Q2	Do you handle your data with a database in your department?	2(9.09%)	20(90.91%)

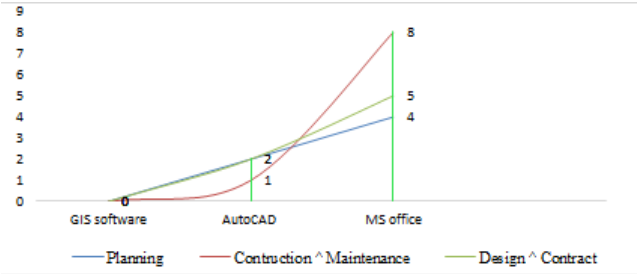
Results represented that majority 20 (90.91%) of the total respondents in all departments answered no to the question "Do you handle your data with a database in your department", there is no database for handling and performing their tasks. 2(9.09%) of the total respondents answered yes to the Q2.

This shows that Mekelle Road Authority (MeRA) has a very limited use of database systems. As such, there is no efficiently managed data or information of roads in the authority because there is poor data management system for data handling, for that case, our investigation shows that data and information are scattered in different departments or sections; as such there is data redundancy, inconsistency, integrity problems, and backup and recovery problems. Therefore, Mekelle Road Authority (MeRA) as a whole has a problem to search, extract, visualize and update roads information.

The type of software used in Mekelle Road Authority (MeRA) to process the activities

Q3. What type of software is used to process the activities of MeRA for planning and management aspects?

Figure 7: Type of software used in MeRA as responded by all the Departments.



As we can see in Fig. 7, 17 (77.27%) of the total respondents responded that they use only MS Office software in particularly MS Word and MS Excel to the question" What type of software is used to process the activities of MeRA including planning and management aspects?" 5 (22.73%) of the total respondents answered both Auto CAD and MS office to Q3. None of the total respondents in all Departments answered none, none of them use GIS software to Q3, although they deal with spatial data.

Results suggest that MS office is used by most of the data managers and top managers of the office to handle the roads information, generate reports of roads and prepare designs for the surveyed road data proposed for maintenance and constructions (e.g. to produce paper map). Some technical mangers in the Planning Department used Auto CAD to draw/mark using colored line symbols in order to identify where the roads are maintained or constructed in existing road map which was designed using Auto CAD software. This process is planned to be used for the next five years. Technical workers in the Design and Contract as well as Maintenance and Construction Departments rarely use Auto CAD software to measure length and width of roads. From the above information we can conclude that, the Office of Road Infrastructure often use MS Office software to process their activities. As a result, they are limited in analyzing and visualizing their data, such as visualizing location of roads dynamically. This mentioned task is done in a very time consuming way and sometimes there is discrepancy between actual measurement of certain values from surveyed data and those who used Auto CAD software to produce paper map.

Table 4: GIS tools in Mekelle Road Authority.

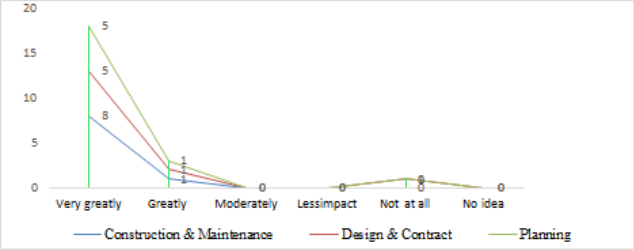
No.	Questions	Yes	No
Q4	Can Web services facilitate the activities of road infrastructure management and planning?	22(100%)	0(0%)
Q5	Do you have GIS product maps that indicates road features?	22(100%)	0(0%)

In questions four and five all the respondents in all Departments replied positive answer, they believe that web services can facilitate the processing activities roads and there is a map for road features.

These results show that, although web services is believed to facilitate the processing activities of road infrastructure management and planning, the authority does not utilize it. As a result, the Mekelle Road Authority is limited in using spatial analysis of roads information both in space and time. They cannot for instance quickly search for specific data of roads, timely-update the road information when there is modification and generate reliable, accurate and timely spatial information of roads.

Q6: To what extent Web services can support Road Management and planning processing activities?

Figure 8: Extent of SOA Web services in facilitating managements function.



As we can observe in Fig. 9, 8(36.36%) participants from Construction and Maintenance Department, 5(18.18%) participants from Design and Contract Departments and same 5(18.18%) participants from planning answered greatly to the question Q6. A total of 1(4.55%) respondents in all Departments answered greatly to the question "To what extent web services can support road management and planning processing activities?" Only 1(4.55%) from Design and Contract Department answered not at all to Q6.

This result indicates that almost all respondents but one from the Design and Contract Department believed that web services can facilitate Road Management and planning functions very greatly. They have confidence in that; GIS tool can support road management and planning activities and allow access of spatial analysis by using interactive analytical tools anywhere at any time with Internet connection easily. Not at all is answered by one participant. The data mangers' level of awareness for SOA web services to support road management and planning is almost very high.

Results and discussion for the system development web services

Use case diagram for Mekelle Road Management and Planning

Use cases focus on the system users, user actions and the system processes that show an abstracted view of what the system can do to a user [20]. When users or planners come to know what a system should do for them, it demonstrates the interaction between user and a system for MeRA, it is defined the actors needed to use the system to meet the effective management of road infrastructure functions.

Figure 9: Use case diagram for road management and planning system.

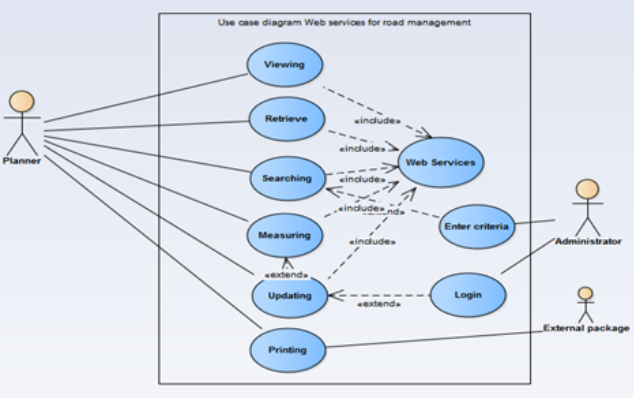
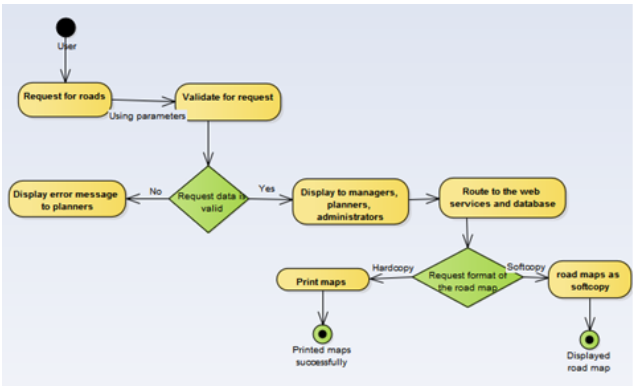


Figure 10: activity diagram for searching services.



The user or planner can make a request for specific road information using the query parameters from the feature class. Having searched, if it gets, it will draw the map and can print it unless it returns to the request section. Data managers request roads information using query parameters. If he/she is success, map will be displayed and he/she can measure length of roads and print option also provided unless it returns to the request section.

User Interface for MeRA Management and planning

Figure 11: User Interface for the web service for Mekelle road management and planning.

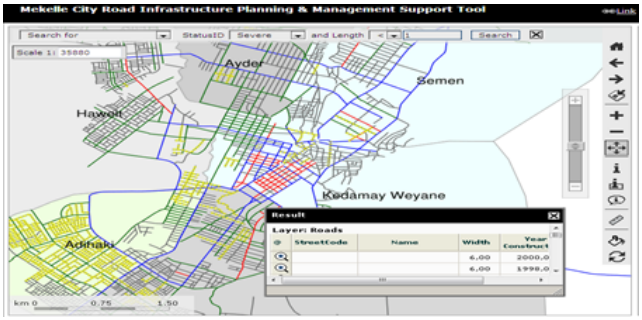
We can open the system via three screen resolutions, small resolution (740x520), medium resolution (860x600), large resolution (980x700) and very large resolution (1024x768). Then we can search the type of data we want display as spatially and textually as integrated way.

Results of Basic Query Implementations for Mekelle roads' information

Below is some of the searching examples implemented queries by for Mekelle roads' information prototype in screenshots.

Question 1: Where are the roads whose status is severe with length less than one?

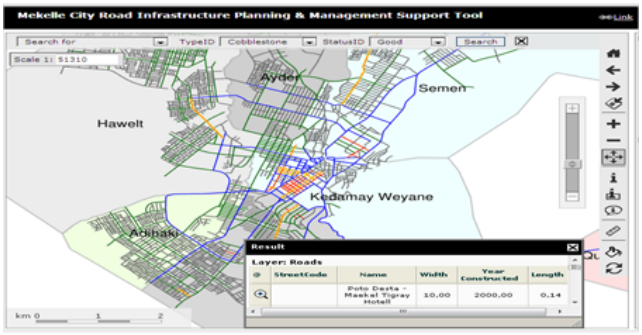
Figure 11: Result for question one- status of roads with sever status where its length is less than one.



This query displays the road type where its status is much damaged or sever. The yellow color line features in the displayed map show the result of the query and the table shows the result of the query that contains attribute information.

Question 2: Where are the cobblestone roads where its status is good?

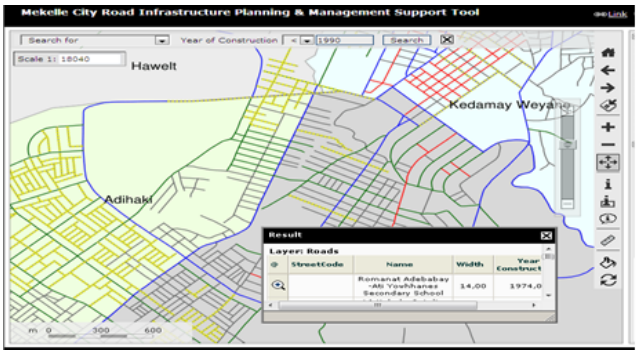
Figure 12: Result for question two- cobblestone roads where its status is good.



This query displays the cobblestone roads where it's good. The yellow color line features in the displayed map show the result of the query and the table shows the result of the query which contains textual information.

Question 3: Which roads are constructed before 1990 Ethiopian functional year?

Figure 13: Result for question three- roads which were constructed before 1990 Ethiopian calendar.



The yellow color line features show the result of the query- the type of roads which were constructed before 1990 Ethiopian functional years.

CONCLUSION

There is no dedicated integrated system to handle data and information in Mekelle Road Authority. As a result, data redundancy, data inconsistency, data integrity problems, data searching, data visualization, and backup and recovery are common problems. 87.91% of the total respondents responded that there is no database system to maintain and provide spatial information for planning, managing and decision makings in the Office.77.27 % of the total respondents replied that the type of software often used is only MS Offices; it does not utilize any GIS web services to process and manage spatial data. So, the office is limited in analyzing and visualizing spatial data such as visualizing location of roads dynamically and searching (querying) roads' information. Therefore, the current situation of the Road Management and planning is suffering from long processing time, less productivity, no support of spatial analysis, searching problems, updating problems and it involves a lot of paper work. This contributes to slow decision makings in the office. Here is a need for a SOA Web services which can help organizing the data, provides timely information on road infrastructure to be accessed, visualized and analyzed by road infrastructure managers and other potential users.

The deliverables of this study is to develop the framework design of road infrastructure management. Framework design is important to data managers and planners of roads to know what a system should do for them. It demonstrates the interaction between the user and a system such as showing the capability to search, retrieve, select, identify measure, and print road data. In addition to this, due to well geodatabase design, there is no data inconsistency, backup and recovery problems rather it can save time, effort, and cost of these processes. These were developed using the UML, PostgreSQL, QGIS and ArcGIS technologies.

The SOA Web services prototype for Mekelle Road Authority to facilitate the management and planning activities was developed using Map Server technology; map sever that uses p-mapper can facilitate easily portray of geographic data on web. The p-mapper framework is intended to offer broad functionality and multiple configurations in order to facilitate the setup of a Map Server application based on PHP/Map Scripts. The new system is simple to use and it facilitates searching road information in space and time. In addition the interactive analytical tool improves the Road Management and planning activities such as measuring, identifying, printing, selecting road data timely.

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