Geographical Information Technologies for Road Infrastructure Maintenance in Uganda

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Abstract

This thesis is a documentation of research on Geographical Information Technologies (GITs) as decision support tools in Road Infrastructure Maintenance (RIM) in Uganda. The main objective is to develop an operational framework within which the use of geo-information technologies can be enhanced as decision support tools in road infrastructure maintenance works of Uganda. Specifically, the research identifies the gaps and limitations in the use of and access to GITs for RIM and defines an algorithmic framework to accentuate the use of GITs in RIM. The research undertook a participatory multifaceted approach that included a review of documentation both in academia, in form of articles, journals, books, reports and research theses and also reports and documents prepared by the road infrastructure maintenance sector. Participant observations, field visits and measures, interviews and workshops were also triangularly employed to obtain the inherent answers. Content and GIS analyses were made to arrive at the findings that are documented in the papers which are part of the thesis.

The gaps to using GITs in RIM have been found to include the lack of standardized datasets to address key nation-wide and local maintenance requirements, challenges on coordinating how geospatial data are acquired and utilized and the collection of duplicate data sets at the local and national levels. Also, the present institutional arrangements do not permit the formation of lasting partnerships and operating under a coordinated GIS infrastructure. The limitations to access of GITs in the sector include; the absence of policies for accessibility and standard use of GITs, lack of infrastructure to support utilization of geographic datasets, unavailability of and limited accessibility to geographic data, lack of geospatial capacity at individual and organizational levels and the digital divide. A nondeterministic algorithmic framework approach to the accentuation of GIT usage in RIM has been suggested. This framework involves strategies on; developing a policy on data collection guidelines emphasizing the use of GPS, satellite imagery and GIS, continuous undertaking of capacity building in the benefits of GIT use and the science involved, establishment of Local Spatial Data Infrastructures (LSDI) for road maintenance data and setting aside yearly budgets for the defined activities. In this framework, the dynamic segmentation data model is considered a superior data storage strategy for road maintenance data within the GIS. Dynamic Segmentation is the process of transforming linearly referenced data (also known as events) that have been stored in a table into features that can be displayed, queried and analyzed on the map through computations. It allows for the location of multiple events stored with linearly referenced attributes without any duplication with route geometry and in effect supports sharing of network infrastructure with different applications

The thesis has been organised in four parts. The first part is the introduction to the research which provides a background, discusses the conceptual issues related to GITs, the current status of GITs in the RIM sector, the objectives to the research and the methodology adopted to achieve those objectives. Part 2 is a review and contextualisation of related research, Part 3 are the published papers in their original form and Part 4 is a brief discussion of the attached papers, the researcher's contribution to-date, the way forward to the doctoral thesis and final remarks.

Keywords: Data model, Decision support, Geographical Information Technologies (GITs), Road Maintenance, Uganda.

Acknowledgement

I am privileged to have the opportunity to thank whoever has somehow made a contribution to the success of this research to date. The almighty Lord who has kept me alive and energetic to perform these works, I will always give you the glory!

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Lastly, I am indebted to my family, for the times they have endured without my physical presence as mother and wife, especially to the latest addition Brianna! Brianna has kept jolly and accommodative in my absence, an aspect of her that kept me comfortably writing this thesis away from home.

May God abundantly bless you all!

Mazzi Lydia Kayondo – Ndandiko
Karlshamn April 2011

…I dedicate this thesis to my family, Brianna, Bridgette, Bruno and Charles…
…So that you may know, that in my absence, I was making these ends meet...

Preface

This thesis builds from the author's master's research where she investigated the relationship between information requirements and data availability in the case of transport planning in Uganda. The problem addressed at the time was centred on the transportation system of Kampala being faced with many challenges. Research has assigned these challenges to lack of knowledge on the part of planners as to which data to use, data not being available and even the available data not being put to use in planning for a better system and services. This was essentially because this data did not suit the requirements for planners. *However, today, this situation is being addressed through the ongoing National Spatial Data infrastructure (NSDI) studies taking place in the country. A Spatial Data Infrastructure (SDI) is a framework of policies, institutional arrangements, technologies, data and people that makes it possible to share and use geographic information effectively. Although individual attempts to affect SDIs have been on for quite some time, at the moment, there is an ongoing study at the national level that was commissioned to assess NSDI for monitoring development outcomes. This study is at the stage of defining roles and responsibilities to cater for the various sections of the NSDI. The question of its (NSDI) funding is however still a hassle to come by thus far.* To address the research problem then, the researcher sought to propose some guidelines for improving the utilization of geo information within the transport domain in Kampala. These devised guidelines were logically derived from the challenges faced with the utilization of geo information. The challenges were mainly organizational but also technical in nature. These guidelines included, struggle to warrant political favour, formalisation of collaborations among the different organisations, streamlining of organisational roles and responsibilities, documentation of data, developing of data standards, maximizing the donor funded projects and combining several funding mechanisms to facilitate data update. That research concluded that because of the complexity of the transport sector demands, there was no single approach to collecting, analysing, displaying and dissemination of geospatial transport information. From that research, a manuscript chapter entitled "SDI Requirements for Transport Planning: A Case Study of Kampala Uganda" has been accepted for publishing in the book, "Recent Advances in GIS and Remote Sensing Analysis in Sub-Sahara Africa" by the Nova publishers.

In a continued process from the master's programme, this research then seeks to investigate the use of Geographical Information Technologies (GITs) as Decision Support Tools in Road Infrastructure Maintenance (RIM) in Uganda. Despite the tremendous advances in geospatial technology and the increase in availability of spatial data, geographic information technologies have not taken foot in the road maintenance sector of Uganda. The gaps and limitations in the use of GITs for RIM have been analysed to relate with the institutional challenges limiting the attainment of basic data requirements for transportation planning from the previous research. These have been discussed in paper II of this thesis. In paper III, a framework to enhancing the use of GITs for RIM has also been suggested. Paper IV discusses a Low cost GIT based mapping methodology that could assist decision makers at the preliminary decision making level of maintenance programs. The three papers (I, II and III) included in this thesis have been published as conference papers. Paper IV is a manuscript that has been submitted for presentation at the 1st Conference on the Advances in Geomatics Research scheduled for 4th-5th August 2011. The reference details to these papers are as below.

I Mazzi,L., K., Tickodri, S., S., T., and Bax, G., (2009). Geographical Information Technologies as Decision Support Tools in Road Infrastructure maintenance in Uganda. In proceedings of the 9th AfricaGIS international Conference: "Geo spatial Information and sustainable development in Africa; Facing Challenges of Global Change", Kampala, Uganda, 26th - 30th October 2009. ISBN: 9970-814-17-6.

II Mazzi,L., K., Tickodri, S., S., T., and Bax, G., (2010). An Overview of the Gaps and Limitations in the Utilization of GITs for Road Infrastructure Maintenance in Uganda. Presented at the 5th ESRI Eastern Africa User Conference (EAUC), Transportation and Utilities. Safari Park Hotel, Nairobi - Kenya. 10th - 12th November 2010

III Mazzi,L., K., Tickodri, S., S., T., and Bax, G., (2011). Algorithmic Incorporation of Geographical Information Technologies in Road Infrastructure Maintenance in Uganda. Presented at The Second International Conference on Advances in Engineering and Technology (AET2011). Theme: Contribution of scientific research in development.1(C) Information and Communications Technology and Policy (ICTP-1) pp 242-248. Imperial Resort Beach Hotel, Entebbe, Uganda. January 30th – February 1st 2011. ISBN: 978-9970-214-00-7

IV Mazzi,L., K., Bax, G., and Tickodri S.S.T., (2011). Low Cost GIT Based Technology for Preliminary Road Maintenance Decision Support. To be presented at the Advances in Geomatics Research Conference on 3rd -4th August 2011, Kampala, Uganda.

As a background to this research but not included in this thesis is the manuscript book chapter accepted for publication by the Nova publishers. Its details are as below;

V Mazzi Lydia.K.N. and Gidudu, A., "SDI Requirements for Transport Planning: A Case Study of Kampala Uganda" in Recent Advances in GIS and Remote Sensing Analysis in Sub-Sahara Africa

The research will eventually progress to a PhD on assimilation of the stakeholders' contribution to the developed framework and on development of a prototype GIS-T dynamic segmentation data model for road maintenance in Uganda.

List of Acronyms

ADEOS	Advanced Earth Observing Satellite
AVL	Automatic Vehicle Location
CAA	Civil Aviation Authority
CCD	Charge Coupled Device
CEDAT	College of Engineering, Design, Art and Technology
DBMS	Database Management System
DDM	Data Dialog Modelling
DGMS	Dialog Generation and Management System
DSS	Decision Support Systems
ETM+	Enhanced Thematic Mapper plus
GDP	Gross Domestic Product
GI	Geographical Information
GIS	Geographical Information Systems
GIS-T	Geographical Information Systems for Transportation
GITs	Geographical Information Technologies
GLCF	Global Land Cover Facility
GMMS	GIS Based Maintenance Management System
GoU	Government of Uganda
GPS	Global Positioning Systems
ICT	Information and Communications Technology
IQL	Information Quality Level
IRI	International Roughness Index
IRS	Indian Remote Sensing
ITS	Intelligent Transport Systems
KBS	Knowledge Based System
KCC	Kampala City Council
KML	Keyhole Markup Language
LC	Local Council
LG	Local Government
LISS	Low Imaging Sensing Satellite
LRP	Location Reference Point
LRS	Location Reference System
LSDI	Local Spatial Data Infrastructure
MBMS	Model Base Management System
MDGs	Millennium Development Goals
MIS	Management Information Systems
MoLG	Ministry of Local Government
MoWT	Ministry of Works and Transport
MRSAC	Maharashtra state Remote Sensing and Application Centre
NDP	National Development Plan
NISDIC	National Interagency Spatial Data Infrastructure Committee
NPA	National Planning Authority
NSDI	National Spatial Data Infrastructure
NWSC	National Water and Sewerage Corporation
OPRC	Output Performance-based Road Contracts
PAN	Panchromatic
PCI	Pavement Condition Index

PEAP	Poverty Eradication Action Plan
PMIS	Pavement Management Information System
PROME	Project Management Engineering
PWD	Public Works Department
RAFU	Road Agency Formulation Unit
RAMPS	Road Analysis Management and Planning Software
RAMS	Road Asset Management System
RGB	Red Green & Blue
RIM	Road Infrastructure Maintenance
RIMS	Road Information and Management System
RMS	Road Management System
ROMDAS	Road Measurement and Data Acquisition System
RS	Remote Sensing
SDI	Spatial Data Infrastructure
SDSS	Spatial Decision Support Systems
SLC	Scan Line Corrector
SOI	Survey of India
TOR	Terms of Reference
TRB	Transport Research Board
TTCA	Transit Transport Coordination Authority
UBOS	Uganda Bureau of Statistics
UEB	Uganda Electricity Board
UETCL	Uganda Electricity Transmission Company Limited
UML	Unified Modelling Language
UNRA	Uganda National Roads Authority
WTC	World Trade Centre

Part 1 - Introduction

1.1 Background

A well maintained transportation system of a country plays a pivotal role in its infrastructural development thus promoting sustainable development. Economically, transport is a livelihood of cities, and in most countries, including developing countries, cities are the major sources of the national economic growth (World Bank, 2002). This is to imply that the economic health of a region is directly linked to mobility. Transport accounts for an appreciable percentage of a country's Gross Domestic Product (GDP) and as such is central to development.

The provision, operation and maintenance of the physical infrastructure of a transportation sector and its related social services require a prior knowledge and manipulation of geo-information. Geospatial data are a foundation for relevant and critical information for planning, engineering, asset management, and operations associated with every transportation mode at all levels of government and administration, Transport Research Board (TRB, 2004).

The management of road transport, since it is the most widely used mode of transport in Africa, plays an important factor in the country's development. The transport sector in Uganda contributes significantly to the economic growth and poverty eradication in the country through various ways, especially, through trade and tourism. It (the transport sector in Uganda) comprises of roads, railways, air and inland waterways. Road transport is by far the most dominant mode of transport in the country, carrying well over 90% of passenger and freight traffic and serving as a true backbone supporting the country's economy, Uganda National Roads Authority, Terms of Reference (UNRA-TOR, 2007). Roads provide the only means of access to most of the rural communities and effective management of this asset is vital to the Government of Uganda's strategy for economic development and poverty eradication. The absence of a fully functional railroad to handle both freight and long distance routes has created strain on the road infrastructure in Uganda.

There have been many cases of poor transport services in Uganda as documented by; Grimaud et al. (2007), Transit Transport Coordination Authority (TTCA, 2004), and Mukwaya (2001). The road infrastructure was developed in a chaotic manner, with no plan for a coordinated and rationalized use of modes and routes (Mukwaya, 2001). As a result, it has suffered from negligence leading to road infrastructure failure. Attempts to maintain roads have frustrated users as they (the roads) almost immediately develop pot holes after repair. Worse still, road maintenance has proven ad hoc, thus making the transport system unsatisfactory.

Dimitriou and Banjo (1990) discuss transport problems of third world cities. They include traffic congestion, impacts to the environment, and high road accidents. Even today, Uganda still faces problems of traffic congestion, high road accidents, weak institutional support leading to poor definition of the problem at hand and differing technology transfer priorities in problem resolution.

Nowadays, however, the need for preventive maintenance is being appreciated in Uganda and plans of making it a priority are in place (Robinson and Stiedl, 2001). Luyimbazi (2007) indicated that maintenance needs are based on road inventory, condition and traffic data, all of which can be effectively collected and managed using Geographical Information Technologies (GITs).

The understanding of GITs, effective use of geographical information and the knowledge of their advantages is critical to the planning and decision making process for asset management departments. Because a well maintained road network asset is very important for the economic development of the nation, Road Infrastructure Maintenance (RIM) is a prerequisite for the successful management of roads. The use of Geographic Information (GI) that is collected, managed and analyzed using GITs is very useful in decision making for RIM. GITs are commonly referred to as Information Communication Technology (ICT) tools used in the collection, management, maintenance, manipulation and presentation of geographic data and or information (Ehrensperger et al., 2007). More recently, it has become clear that GIS, together with Global positioning systems (GPS), aerial photography, Remote Sensing techniques, and other spatially related tools for decision making, comprise a larger array of complementary tools that can be grouped together under the more comprehensive rubric of "geographic information technologies" (GIT) (Teresa M. Harrison et al., 2007). The use of these technologies is known to simplify decision making to a non technical level and to support the stakeholders in sustainable-oriented decision making. Embracing and continuing to develop a flexible, methodological framework for the integration of decision-supporting technologies with infrastructure is fundamental to supporting effective incorporation of spatial data in decision-making (Cartright, 1993) as cited in Masser and Onsrud (1993).

Uganda is beyond the first appearances of GIT, when only highly qualified professionals could handle them. Today, advances in technology are tremendous (Ehrensperger et al., 2007). A wide range of GIS is available ranging from high cost server based to low cost user-friendly desktop software. The sector has noted the increase in the availability of spatial data. The spatial and temporal resolution of remote sensing data has impressively increased, and more data are now freely available. The most outstanding advancement has probably been the development of the Internet and web GIS which has opened up new opportunities such as access to real time maps, cheap and frequent data updates and worldwide sharing of spatial information. Disseminating spatial information on the Internet through web-based GIS improves the decision-making processes (Jain and Sharma, 2005). Through graphic representation and spatial analysis, the use of GITs would help to make RIM processes understandable to decision makers and lay persons.

Use of GITs is increasingly shifting from reference tools to dynamic decision making tools. This shift has been triggered by, among other factors, emergency situations such as the World Trade Centre (WTC) attacks of September 11 200l (Teresa M. Harrison et al., 2007). This attack became a catalyst for change in the use of GITs for almost all relevant disciplines transportation inclusive. Most of the data required for road maintenance is spatial in nature, making GITs relevant in road maintenance. Road maintenance in Uganda has presented a big challenge and yet there is no research that has been undertaken to contextualize the GIT requirements for improving road maintenance. Maintenance attempts have extensively centered on fixing of potholes when observed. However, without use of appropriate data and data models, road maintenance activities are bound to persist as costly and time consuming. There is no comprehensive methodology or framework for addressing both the technical and non-technical issues affecting GIT implementation. The overall aim of this research is to define a framework that will work towards enhancing the use of GITs as decision support tools in road infrastructure maintenance works in Uganda. This thesis gives a description of the road maintenance sector in Uganda; it discusses the gaps and limitations facing these organisations as they seek to utilise GITs in RIM (Paper II). Basing on these gaps, the thesis suggests an algorithmic approach in form of a framework to accentuate the use of GITs in RIM (Paper III). As part of the thesis documentation is an introduction to a low cost GIT based technology for preliminary road maintenance decision support (Paper IV) and a brief of the available freeware and open source software to manipulate GI data / products (Paper I)

1.2 Geo Spatial Technologies as Decision Support Tools

Geo Information Technologies are a set of specialized Information and Communications Technologies which help to collect, manage and analyse data about the resources, landscape features, and socio economic characteristics of an area in both space and time (Ehrensperger, et al., 2007). They provide an important feature for communication, dissemination and knowledge sharing on account of their capability to facilitate display and visualization of spatial data. GITs include four basic spatial tools, namely, Geographical Information Systems (GIS), Global Positioning Systems (GPS), Remote Sensing (RS) and web based tools such as Google Earth which provide new ways of sharing information and visualizing of near real time data. Figure 1-1 shows a graphical example of available GIT tools, including a) Nokia GPS network rover receiver with GIS software for mobile mapping b) Satellite image, c) Trimble GPS equipment, d) Aerial photograph, e) Earth globe instancing Google Earth and f) A satellite surveying the earth.

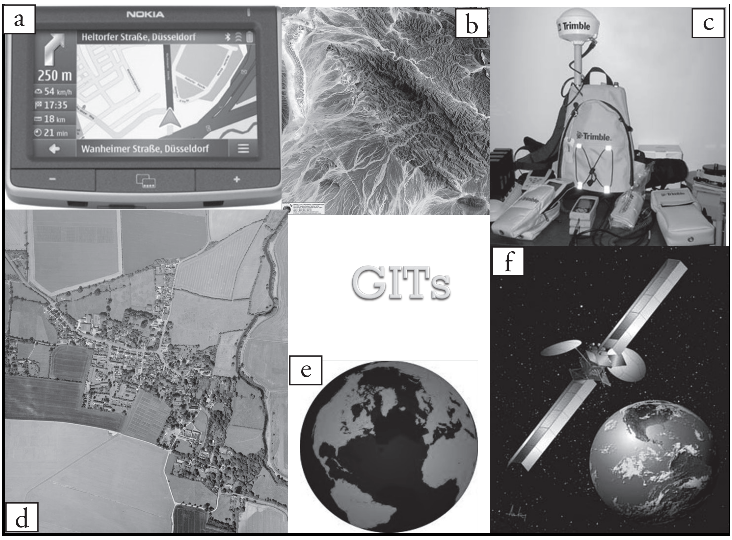

Figure 1-1: Examples of GITs

GIS facilitates storage, management and analysis of geographically referenced data, integrating common database operations with unique means of visualization and the geographic and analysis potentials of maps. It assists users in spatial analysis and provides a base for interpreting how physical, social and economic factors interact in space. GIS can effectively be used as a tool in the Spatial Decision Support System (SDSS) of road infrastructure in Uganda. A SDSS is an interactive, computer-based system designed to support a user or group of users in achieving higher effectiveness of decision making while solving semi-structured spatial decision problems.

GPS are satellite based positioning systems for capturing locations of sample points such as road junctions, potholes or larger features (land marks) on the road. These other landmarks may later be used to reference satellite images or other spatial data layers. Remote Sensing on the other hand is the detecting of the earth's surface from satellites and airplanes by making use of the properties of electromagnetic waves emitted, reflected or diffracted by the sensed objects. It provides images of the earth's surface that can be used to identify especially different types of land cover.

Mapping and cartography are a discipline and science with a long historical background, which dates back probably as long as the history of the written word (Ehrensperger, 2006). They are a traditional approach of GITs, which uses maps and sketches of features in the geographic space to carry out spatial analysis.

Advantages associated with the use of GITs are improved mapping, greater efficiency in retrieval of information, faster and more extensive access to the types of geographical information important to planning, improved analysis, better communication to the public, and speeder access to information for various application processes. Their implementation however is associated with some key issues to consider (Ehrensperger, et al., 2007). These include; Relevance of content: there is a need to identify the various stakeholders to help in the definition of the content in the GIS. Appropriate technology: a crucial aspect of successful GIT implementation is accessibility which includes costs of hardware, software and data. Also, multi disciplinary systems have become a prerequisite for infrastructure management. For instance, road infrastructure maintenance requires data from utility organisations, e.g., water and electricity all of which require integration. Further still, one should consider the strengthening of stake holder's motivation to work together, e.g. across sector ministries and or departments and this is to do with the institutionalization of GIT.

1.3 Transport Services in Uganda

The transport sector in Uganda consists of four major modes; i.e., air, road, railway and inland water transport. Road transport is by far the most dominant mode of transport within the country, carrying well over 90% of passenger and freight traffic and serving as a true backbone supporting the country's economy Uganda National Roads Authority, Terms of Reference, UNRA-TOR, (2007). Roads provide the only means of access to most of the rural communities making its effective management vital to the Government of Uganda's strategy for economic development and poverty eradication. Uganda's Road Network comprises:

- 10,800km National Roads under the responsibility of the Ministry of Works and Transport (MoWT) through the UNRA. About 2700km are paved and the remaining 8,100 gravel;
- 27,500km District roads under the responsibility of Ministry of Local Government (MoLG);
- 4,300km Urban Roads under the responsibility of Urban Councils; and
- 30,000km Community Access Roads under a lower tier of Local Government responsibility (LC III); (Road Fund, 2011)

The Government is currently implementing a programme of continuous upgrading of key gravel roads to bitumen standard. These roads are characterized by bad road surfaces, potholes, poor road designs and inadequate road furniture. The government structure of Uganda is composed of 2 tiers, namely Central Government (GoU) and Local Government (LG). The GoU executes its functions through ministries which receive their mandate from parliament. The Ministry of Works and Transport is responsible for the planning, development and maintenance of the classified road network in Uganda. The LG structure consists of districts governed by autonomous district councils and urban areas governed by autonomous urban councils. The local government act of Uganda was effected in 1997 to decentralize functions, powers and responsibilities, including the devolution of road maintenance services of rural, district, urban and community roads to local and urban authorities. The district and urban authorities are responsible for the maintenance of the district and urban roads respectively. Even though this act allows districts to fully implement routine and periodic maintenance activities, rehabilitation is still handled by the central government through the MoWT. As a further decentralization strategy, the MoWT is planning on issuing out Output Performance-Based Road Contracts (OPRC) where the contractor decides what to do, when to do it, how to do it and where to do it in order to achieve the client prescribed service levels.

1.3.1 Road Infrastructure Maintenance in Kampala

Road infrastructure maintenance in Uganda involves a number of organisations; The Ministry of Works and Transport, Uganda National Roads Authority, road consultants and contractors. The Local governments and donors also play a part in some circumstances. The MoWT has the constitutional mandate to set policy, regulate, set standards, and provide technical guidance and monitoring to the construction industry. Road infrastructure maintenance falls under the construction industry. The Uganda National Roads Authority is responsible for development and maintenance of national roads. The district and urban authorities are responsible for construction and maintenance of the district and urban roads respectively. All districts are staffed with engineers, planners and surveyors. Since the establishment of the UNRA, the district engineers are answerable to UNRA for the national roads within their jurisdiction. A maintenance scenario in Kampala for example, Kampala City Council (KCC), a local government organization, is charged with the responsibility of maintaining district roads within the city. Depending on the size of road and the scope of works required, KCC normally decides whether or not to perform maintenance works using in house equipment and personnel or contract based road maintenance. In the latter method, a private contractor is often procured and hired to perform the works under direct or indirect supervision by KCC. Under indirect supervision, a private consultant company is assigned supervisory role on behalf of the client and this normally depends on the project size and availability of funds. The community access roads are a responsibility of the lower local governments and their maintenance is often community based.

1.3.2 GIT Usage for RIM in Uganda - The Problem

The desire to use GIS by the MoWT in the management of national and district roads was evidenced by the commissioning of a project known as Management Information Systems (MIS) in 2006. This project was planned to apply GIS for monitoring cross-cutting issues in the road sector. The Road Analysis Management and Planning Software (RAMPS) was integrated with GIS and was applied mainly for reporting various attributes for road maintenance. Today, the Uganda National Roads Authority, which is charged with the management of national roads, also uses GIS for reporting. Presently under the UNRA, there is an ongoing project of building a national roads databank for the country. The establishment of the Road Agency Formation Unit (RAFU) in 1999 saw the transfer of the management of capital (development) projects from the MoWT to this semi-autonomous unit, the UNRA. In accordance with this policy and in order to improve the efficiency and effectiveness of its road network management the GoU also decided to introduce an Output and Performance-based Road Contracts system. This system of performance-based contracting is designed to increase efficiency and effectiveness of road asset management and preservation. Therefore, the contractor is supposed to decide what to do, when to do it, how to do it and where to do it in order to achieve the client prescribed service levels. The pilot application of this strategy is planned on a network of approximately 1,500 km of selected national roads network in eastern Uganda i.e. Jinja, Tororo and Mbale maintenance stations.

In order to adequately prepare for the replication of this OPRC system to the rest of the national road network of approximately 9,000 km, RAFU now UNRA needed to set up a comprehensive Road/Bridge Management System (RMS) with a road data bank to be used accurately for determining the funding requirements for road maintenance, development and rehabilitation. Accordingly, the Ministry decided to commission consultancy services to assist in collecting planning data on the national road network and set up a comprehensive geo-referenced road management system that can be used to determine the maintenance, rehabilitation and development needs of roads, bridges and other road network assets. Roughton international and PROME consultant ltd are providing these consultancy services. Apparently it is at this project level that GITs are to an extent being realized in the collection and management of road maintenance data. For example, the Road Measurement and Data Acquisition System (ROMDAS) is being used to video-log the road condition in a road inventory survey undertaken by the project in Uganda. The ROMDAS is a surveying vehicle that consists of several measuring instruments including a gyroscope, GPS receivers, bump integrator, etc and a video camera mounted in the vehicle. It also possesses software to process the collected discrete data. It is used basically for inspection of the road network (Mihic and Ivetic, 2010). PROME is just one of the consultant companies involved in road maintenance activities in the country. Several other consultant and contractor companies without GIT knowledge and expertise are similarly involved in various road maintenance activities.

In reality, GITs are being underutilized in the RIM decision making processes. In Uganda, the decision to perform maintenance works on a road is initially based on; records of past expenditures on the road sections in question, availability of resources and traffic levels along these roads. However, most of the data required for road maintenance is spatial in nature. Luyimbazi (2007) indicates that road maintenance needs are based on road inventory, condition and traffic data. This makes GITs relevant for the purpose. And yet, road maintenance has continued to present a big challenge. There is no research that has been undertaken to contextualize the GIT requirements for improving road maintenance. Maintenance attempts have extensively revolved around fixing of potholes when observed or at worst, when complaints are made via the media. Just like Bishop et al., (2002) articulate, a prerequisite for intervention is a framework of up-to-date spatial information and a user community with both the skills to use specific software products, and an underlying knowledge of spatial information science. Without such intervention involving the use of appropriate data and data models to enhance GIT usage in the sector, the traditional approach to decision making will suffice. And yet this approach is limited by time constraints and wastage of both human and financial resources. The focus of this study is to devise strategies of enhancing the use of geo spatial technologies as decision support tools in RIM in Uganda, as support to the traditional pattern matching (majorly based on human judgement), that has been used over time.

1.4 Research Objectives and Questions

The research has been guided by a general objective and three specific objectives

General Objective:
To develop an operational framework within which the use of geo-information technologies can be enhanced as decision support tools in road infrastructure maintenance works in Uganda.

Specific Objectives:

1. To identify gaps in the use of GITs in the road infrastructure maintenance process of Uganda and the limitations to accessing these technologies,
2. To develop an algorithmic framework that incorporates GITs as decision support tools in road infrastructure maintenance in Uganda and
3. To develop a road maintenance data model based on the road maintenance data requirements in the road infrastructure maintenance sector of Uganda

Research Questions:
The above objectives are being addressed using the following 5 research questions:

i. What are the barriers faced by GIT initiatives in road infrastructure maintenance?

ii. How can the use of GITs be enhanced into the decision making processes of the road infrastructure works to ensure, that decisions in road infrastructure maintenance are based on reliable spatial data?

iii. What is the nature of the data used for road maintenance decision making?

iv. How effectively can the data in iii) above be represented in a GIS?

v. What is the most appropriate GIS-T data model for road maintenance data in Uganda?

1.5 Significance of the Research

The significance of the research can be highlighted in four major ways. The research will create awareness of the potential of geographical information technologies for data collection, management and analysis among the stakeholders in the RIM sector. It will incite them to the availability of low cost technologies and freeware opportunities of engaging in GITs for decision support purposes. In this way, the research is aligned with goal 8 of the MDGs which strives to make available the benefits of new technologies, especially information and communications technologies in developing a global partnership to development. It should be appreciated that achieving global development is difficult unless initiated at a local level.

The research is also well aligned with objective 5 of Uganda's National Development Plan (NDP) 2010/11-2014/15 which has since then substituted the Poverty Eradication Action Plan (PEAP). As has been established, the transport network of a country plays a pivot role to the economic development of that nation hence playing a part in its poverty eradication. Road maintenance strategies are aimed at maintaining and improving the state of the transport network infrastructure. Objective 5 of the NDP endeavours to promote science, technology, innovation and ICT to enhance competitiveness. The research addresses the key binding constraint of low application of science and technology.

The research will expose the gaps and limitations that are affecting the usage of GITs in the road maintenance sector for the responsible offices to deal with. Notice that even though the research is dealing with the road maintenance division, these gaps and limitations are affecting several other sectors that make use of spatial data for decision making purposes. Documenting these challenges is a prospect to having them addressed.

The framework as one of the final outputs of this research shall be a guiding document to the sector on how to enhance the use of these GITs in support of knowledge based decision making. Finally, the research will develop and test a model for road infrastructure maintenance data for Uganda.

1.6 Methodology

The research is multifaceted and participatory in nature. It is participatory in the sense that stakeholders are involved at all stages of the research during interviews, organizational observations, workshops and conferences. The research initially involved a thorough identification of all stakeholders in the road infrastructure maintenance sector. Various literatures relating to GITs, road maintenance, diffusion of GITs etc, is continuously being reviewed. Participant observations, field visits and measures have been carried out. All these methods are employed triangularly to ensure complementarily of findings. The overview is summarized in Figure 1-2. The figure summarizes the methods used, the reasons for their application, labeled as justification, and the output obtained from these methods. A review of literature was necessary at all stages of the research hence the direct arrow from the literature review method to the justification box. Similarly, all the methods employed in the research had a contribution towards the algorithmic framework to accentuate the use of GITs in the RIM sector. Likewise, the conferences attended and the scheduled workshop (see section 4.3) is to contribute to the entire findings of the research.

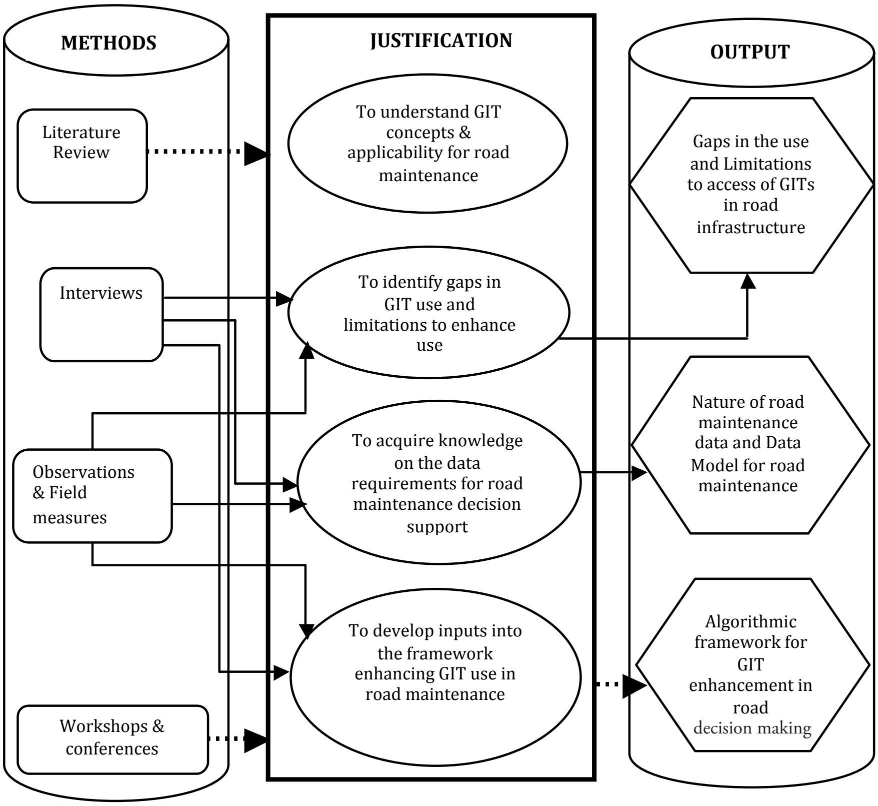

Figure 1-2: Research Design

1.6.1 Literature Review

There is literature documented in journal articles, conference proceedings, books and reports on the applicability and implementation of GITs. This literature is continuously being reviewed in subjects related to, the use of GITs including but not limited to RS, GIS, GPS, ground based mapping and cartography as decision support tools, their institutionalization, adoption, implementation, and success factors, road infrastructure maintenance management works, road maintenance data and all other material in line with modelling GITs for decision support. The content of these documents has been analyzed and used for purposes of this research.

1.6.2 Field Visits and Interviews

Initially, field visits were made to the transport ministry and other stakeholders (UNRA, district engineers, contractors and consultancy firms) for brief illustrations on how decision making is made prior to maintenance of the road infrastructure. In order to achieve objective 1 and 2, the existing systems in these organizations were studied. An analysis of the data used for road maintenance was made. How this data is collected, who manages the databases, the frequency of data collection and similar observations were made. This was followed by interviews using an interview guide. For purposes of pretesting and developing a precise interview guide, informal sessions were initially organized with only a few questions prepared. The intention was to evoke more questions basing on the responses of the interviewee. For this pretesting session, five (5) persons were interviewed using the designed guide and during then, the guide was accessed in terms clarity of questions, time for interview and whether all the required parameters were included in the guide questions. The interview guide was continuously updated until a moment when found satisfactory.

Further questions were continuously generated during the actual interviews as a means of probing interviewees in case of unclear responses. The sampling frame comprised of managers in road maintenance organisations, i.e. MoWT, UNRA, consultants and contractors. The sample size was limited to 3 persons per organization considering that they (organizations) are not heavily deployed in the field of geo information management. However, 5 personnel from UNRA were interviewed. This is because, in UNRA, GIT is being appreciated at a faster rate today. A combination of expert and snowball sampling was used to sample persons with knowledge and demonstrable experience and expertise in the research area, these then recommended others who also met the criteria for inclusion to the interview. This data collection technique was mainly to assist in the generation of the report on the existing gaps in the use of geo spatial technologies in road infrastructure maintenance in the country, to identify the limitations to incorporating these technologies in decision making, and assessing the requirements to having these technologies incorporated in the decision making processes.

1.6.3 Observations

Direct participant observations have been made at the road maintenance organisations especially at the data collection stages of decision making. Populating of the organisations databases and the management of these data were studied for a period of time. This gave an indication of the gaps and limitations of GIT usage and assisted in developing strategies to develop the framework to accentuation of GIT usage in the sector.

1.6.4 Field Data Collection

An independent mapping of the roads as a means of assessing the digital data correctness was made. Using a GPS and laptop, the researcher mapped a sample of roads in the study area for purposes of accessing the currency of the existing databases. A

GIS analysis of these data is intended to highlight the gaps in the data archived in the road maintenance organizations. Through this method of data collection, a low cost GIT based methodology for preliminary road maintenance decision support was also developed.

1.6.5 Workshops and Conferences

The transport sector of Uganda is continuously holding workshops and conferences where their strategic plans and policies are often discussed and reviewed. This is a forum where challenges, limitations and expectations of plans and projects from various divisions of the sector are discussed. During the latter stages of the PhD, the researcher plans to attend workshops and conferences organised by the sector as a means of envisaging the likely possibility of the research intervention being adopted or placed in plan for the future. Additionally, the researcher has made presentations on the PhD work in progress at three (3) internationally organised conferences.

In order to maximize stakeholder participation and consent on the findings and suggestions in place, a workshop of 20 participants is planned (see section 4.3). These shall include members from the RIM stakeholder category that has already been identified, scholars and professionals in the discipline. The researcher will make a presentation on the research findings and recommendations to date. The stakeholders will then have an opportunity to react and have a more harmonized input into the researcher's evolved framework. The intention is to further publicize the findings and recommendations from the research and to access the viability of implementation of the framework basing on perceptions of road maintenance management stakeholders and with scholars of expertise in the subject of GITs in road infrastructure maintenance.

All ethical rules, regulations and laws are adhered to during the execution of the above research methods.

1.6.6 Data Analysis

1.6.6.1 Qualitative Data Analysis

The gathered data from interviews was analyzed using content analysis. Themes were defined and coded based on interview responses and conference discussions (from the international conferences attended). The obtained content was ranked accordingly under the several themes. Depending on the content under the defined themes, it was possible to;

Categorize the gaps and limitations in the use of GITs for road infrastructure maintenance, and,

Hierarchically, depending on frequency of appearance in the thematic content analysis, define a rational algorithmic framework that should enhance the use of GITs as decision support tools in road infrastructure maintenance.

1.6.6.2 GIS Analyses

GIS analyses are being performed on the data. To-date, a combination of datasets was made through vector overlays and raster processing using satellite imagery. This was as an attempt to access the quality of data in use for maintenance visa vie the independent field measures (GPS locations and photos with embedded GPS locations) made by the researcher. Attribute and spatial queries were used to generate statistical summaries of the road inventory and condition data. These findings have been discussed in papers II and III.

1.7 Scope

The study is specifically done in Uganda, with Kampala and Jinja districts as the areas where fieldwork is executed. Kampala was selected being the capital city of the country, and Jinja because of the poor road infrastructure despite its manageable size.

The research involves the development of a framework within which the use of GITs in road maintenance in Uganda should be enhanced. The framework is basically an operational structure within which the organisations involved in the activities of road maintenance decision making can work together to booster the use of GITs.

A GIS-T road maintenance data model for Uganda is to be developed basing on the road maintenance data requirements of these involved organisations. As most of the data is spatial in nature, emphasis will be paved on the spatial data aspects. Some excerpts of the model will be adopted, with scrutiny, from existing data models of countries with similar road maintenance data requirements. The research is participatory, involving the stakeholder organisations in the road maintenance sector in development of both the operational framework and data model.

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Part 2 - RESEARCH CONTEXT

This part of the thesis is intended to contextualize the research by relating it to other research that has been done in the same area. As one familiarizes with the works of previous researchers, it will be important to appreciate the background circumstances of the countries in which these research have been accomplished (that is, in comparison with the country background of this research undertaking-Uganda) hence the context in which this research somewhat differs from what has been accomplished previously. Since the research is pertaining to GITs as decision support tools for RIM, a brief background on decision support systems will be adequate as a preface to contextualisation of the research with the reviewed literature.

2. 1 Decision support systems

A Decision Support System (DSS) is defined as an approach or methodology for supporting decision-making. It uses an interactive, the solution for a specific semi/non-structured management problem. It uses data, provides flexible, and adaptable computer-based information system, especially developed for supporting an easy user interface, and can incorporate the decision maker's own insights. In addition, DSS usually use models and are built (often in consultation with end users) during an interactive and iterative process (evolutionary prototyping process). They require hardware, software, information or data, and should support all the phases of the decision making process, which include, intelligence, design and the choice and implementation phases (Turban, 2001). Figure 2-1 diagrammatically shows this decision making / modelling process.

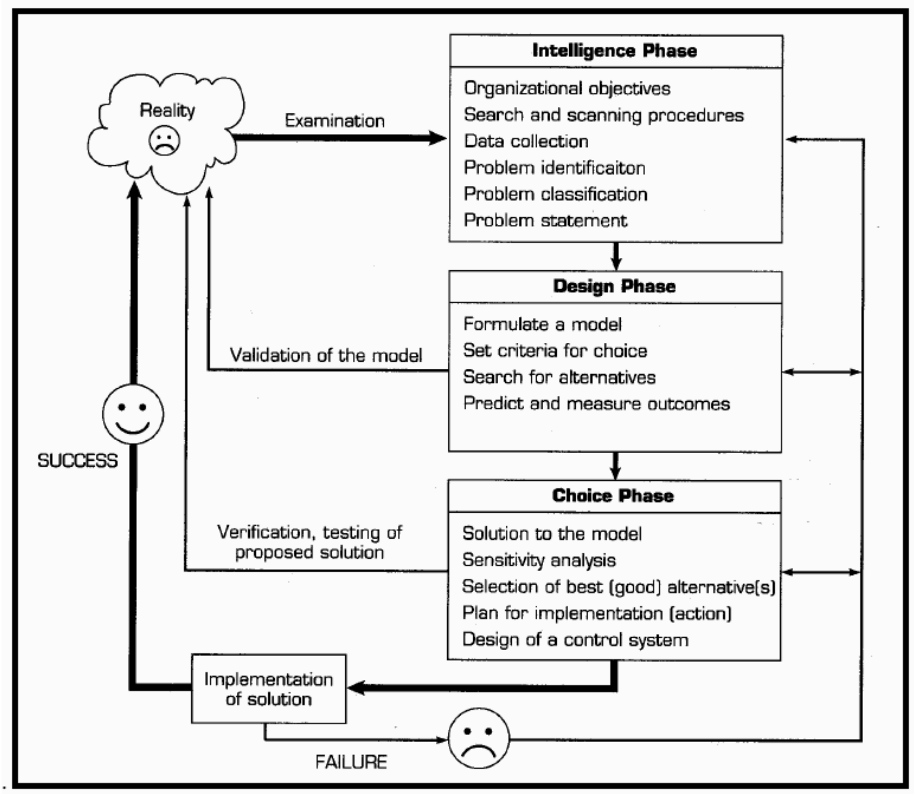

Figure 2-1: The Decision making / Modelling process.
Source: (Turban, 2001)

This description of a DSS necessitates a couple of tools of which GITs have been proven as useful in problems that are spatial in nature. The technology for a DSS must consist of three sets of capabilities in the areas of *data, dialog*, and *modelling* (the DDM paradigm) (Turban, 2001). There should be a balance between the data; dialog and modelling for a spatial decision support system. The focus of this research is on the Data aspect of this DDM paradigm. This aspect concerns itself with considerations of data capture, storage, manipulation, and retrieval. Figure 2-2 highlights the components of a SDSS in a DDM paradigm

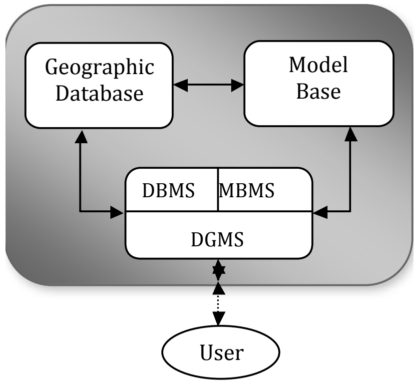

Figure 2-2: Components of Spatial Decision Support Systems: The DDM Paradigm
Source: (Malczewski, 1997)

The Data Base Management System (DBMS) contains the functions to manage the geographic data base; the Model Base Management System (MBMS) contains the functions to manage the model base; and the Dialog Generation and Management System (DGMS) manages the interface between the user and the rest of the system.

2.2 Previous Related Research

Geographic Information Systems, Global Positioning Systems, Remote Sensing and mapping play an important role in all geographic and spatial aspects of the development and management of road infrastructures. Of the three, GIS seems to have attracted most attention and emphasis. Nevertheless, Remote Sensing is viewed as an essential tool for the capture of data subsequently to be incorporated into the GIS and for near real time monitoring of environmental conditions for operational management of the infrastructure facilities. Remote sensing techniques and spatial data analysis through GIS have been used in a number of disciplines as decision support tools.

The use of Geographic Information Technologies is well acknowledged in various studies undertaken by researchers and governments. However, these technologies were only grounded in the early 90s hence the limitation on the scope of literature on previous research in the same. India as a country has greatly advanced in research projects leading to the use of geographical technologies in road infrastructure management. Literature on most of these projects is well outlined in proceedings of the Map India conferences. El-Shair (2003) in a case study of Birkenhead, Auckland illustrated the use of GIS and RS in urban transportation Planning. He used two aspects of transportation planning, i.e., bus routes and stops facilities and assumed that for these facilities to be adequately located in Birkenhead Auckland, 80% or more of the residential and commercial areas in the region should be located within the buffer zone of 300 meters from all routes and stops. His assumptions were examined using buffering, shapearc (writes shape file spatial and attribute information to Arcinfo coverage) and identity tools in Arcinfo, which proved useful. El-Shair (2003) concluded that GIS and RS could effectively be used in urban roads mapping and in urban transportation planning. However, he recommends that another case study should be defined to affirm his findings.

In a bid to evaluate the existing condition of the roads and to suggest needed improvement measures for the roads, so that cost-effective modern technologies could be used to provide higher level serviceability by applying regular and timely maintenance, Rao et al. (2006) developed a GIS Based Maintenance Management System (GMMS) for major roads of Delhi. This development was made so as to benefit from the realistic representation of real-world entities, an organised data structure and the powerful analysis and presentation capabilities of GIS. Similarly, this research is aimed at developing a framework within which GIT benefits can be realised and in turn benefit the RIM sector of Uganda.

Karandikar et al. (2003) outlined experiences out of their project on a GIS based Road Information and Management System (RIMS). In their project, a decision support tool for the Public Works Department, Government of Maharashtra was developed. With the objective of having a more scientific and systematic approach for the archival of maps and retrieval of statistical information, a state wide, up to date digital database of roads that induces efficiency and accuracy in monitoring, management, planning and subsequent development of the road network was developed using GIS. The project was successful due to collaboration between Maharashtra state Remote Sensing and Application Centre (MRSAC), Nagpur, Survey of India (SOI) and Public Works Department (PWD). As a result, district maps used in the creation of raw data for the spatial digital database were obtained. Updating of this raw data was possible with the help of IRS satellite's Panchromatic (PAN) data of 5.8 meter resolution and linear self-scanning Sensor (LISS III) data that was suitably enhanced and registered to PAN data. This research clearly raises two issues, the relevance of GIT aids to maintain up to date spatial data, and, the need for cooperation between departments to achieve GIT institutionalization.

For the situation of Uganda however, updated satellite imagery is not affordable. The freely available satellite imagery is quite out dated. Even for the freely available imagery, hardly any use is being made from them. Besides the high resolution imagery already combined with ancillary data, that is available in Google Earth today, there is free downloadable imagery under the Global Land Cover Facility (GLCF) including the most recent ETM+ images of which the most recent data are however affected by an error due to the Scan Line Corrector (SLC) sensor failure. This research has ascertained 2 reasons so far for the limited utilization of satellite imagery as one of the components of GITs. Firstly, the fact that these imagery are downloadable form various geoportals, there is an obvious limitation of internet bandwidth to accommodate this download. Secondly, interview findings have registered a deficiency in the available expertise to affect the various analyses on satellite imagery. The ongoing research however has attempted to develop a framework that can be used to enhance the use of GITs in road infrastructure maintenance. Otherwise, Karandikar et al. (2003)'s research demonstrated that with ready data availability, GITs, GIS in this case is a reliable decision support tool, which, with road infrastructure maintenance, cannot be an exception.

The evaluation of accident black spots on roads using GIS was successful in India (Mandloi and Gupta, 2003). Data on the road infrastructure of the study area could be readily availed with such attributes as:

- Number of lanes in each direction,
- Approximate number of vehicles per day,
- Type and width of road, among others

Each of the attributes was assigned weights ranging from 0-10 with the factors tending to increase the probability of accidents having lower weights. For the 11 factors used, the total weight was computed as; Total weight = (Individual Weights) x $\frac{100}{110}$ and then assigned to ranges according Table 2-1.

Table 2-1: Prioritization Scheme

Final Weight (%)	Accident Prone Level
80-100	Very Low
60-80	Low
40-60	Medium
0-40	High

Source: (Mandloi and Gupta, 2003)

The need for a similar model in the situation of Uganda cannot be under looked. However, given the background to this research, it is clear that without the practice of using these GIT tools for decision support, even such a model developed at this point in time, noticing the proficiency of the road transport's administration may be more of a bookshelf invention.

A data model (a collection of conceptual tools for describing data, data relationships, data semantics, and the data constraints) for an object-related geo database for Iranian roads network was presented by Dodge and Alesheikh (2003). Dodge & Alesheikh (2003)'s model provides a context within which a GIS can quickly and easily accept the input that a wide range of users need to accomplish their transportation management goals. The model's intention is an initial structuring of transport data and was specified in the Unified Modelling Language (UML). There are 3 categories of GIS-T (Geographical Information System parameters specific for Transportation) models; Network, Process and Object data model, all as their names suggest: Network models are those concerned with the topology of connections and intersections of nodes and arcs of a transportation system. "Instead of focusing on any single element of a transportation procedure, process models seek to organize many elements into a model that defines a process by which some transportation planning or maintenance activity can take place. Object models are those that seek to identify or enumerate as many transportation objects as possible and to logically organize them in such a way that they can be most profitably used" (Dodge and Alesheikh, 2003). Dodge & Alesheikh (2003)'s research defined a data model on the basis of which a transportation geodatabase would be created. In relation to Dodge & Alesheikh (2003)'s research, the ongoing research is specifically dealing with road maintenance data. A proposal for a dynamic segmentation GIS-T data model for road maintenance data has been made based on its obvious advantages. Dynamic segmentation enables the provision of road segments with precise and high value spatial resolution based on their attribute similarity. It allows for the location of multiple events and storage of linearly referenced attributes without any duplication with route geometry. It also offers the possibility for sharing of network infrastructure of different applications within the road maintenance sub sector.

Siddeswar (2003) illustrates the use of GIS in transport management specifically in the management of traffic congestion. He highlights the benefit of effective transport planning using GIS as; ease of traffic movement, lesser time on roads, reduced tempers with driving, increased personal safety and effective transport planning. These benefits have not been realized in Uganda due of the lack of employment of the Automatic Vehicle Location (AVL) technology. In Siddeswar (2003)'s study, GPS technology is effectively used for AVL, with vehicles being equipped with a GPS that gives its accurate position in latitude and longitude. With these details received at a central traffic control room, several analyses on vehicle location are possible. In cases of traffic jam, the system can be made intelligent to generate alternate routes. Also, some of these data can be mined to be very useful later on for various activities of traffic planning and management. This aspect of mining data is in harmony with the Knowledge Based System (KBS) as suggested by Tsou et al. (2000).

Remote Sensing has been used as an application in the extraction of road information. In his study of applying remote sensing for extraction of road information, Manzul et al. (1999) established that all commercially available satellite based sensors at that time were appropriate for identifying roads not less than 35m wide. Therefore, ADEOS Multi-spectral and LANDSAT TM could not be used for identifying a road having for example, a width of 15m or less. However, today, Landsat-7 ETM has 15m resolution in the panchromatic band, meaning that road's details can be studied even much better to date. In the study undertaken by Manzul et al. (1999), the spatial resolution of data was found to contribute more to the clarity of the road than the spectral observation capability. In addition, the surrounding environment along the road was considered to be an influential factor in affecting the difference in reflectance of the road hence affecting the clarity of the road in the satellite imagery. For a developing country like Uganda, where the cost of up-to-date remotely sensed imagery is not affordable, research should primarily focus on inventing a more sustainable and cost effective method of obtaining up to date data on roads. However if the satellite image can be obtained by any means, the rest of the data extraction techniques are the routine functionalities of GIS and remote sensing software, which at the moment, are also a restraint to come by due to the alleged limited expertise in the transport sector of the country. This still puts the ongoing research in perspective in argument there is need for a framework that can strategise on how all these envisaged challenges in using GIT can be dealt with.

Mohammad et al. (2009) have designed a road maintenance data model using the dynamic segmentation technique. This data model has been implemented on the Iranian road network. The researchers base their argument on the fact that developing a successful GIS for road maintenance applications is highly dependent on the design of a well-structured road maintenance data model. Despite its limitations, the traditional arc-node data model was being used in their jurisdiction. In this model, roads are represented as linear features between two nodes with associated attributes. The attributes are integrated such that they are restricted to arcs with similar length and location. These models do not present concentrated and precise road segments efficiently. The arc-node data structure handles the linear feature as an arc using a Cartesian coordinate system with which it is not possible to present road data varying in different parts of arc. The resulting analyses are in effect inefficient and not based on reality when it comes to road maintenance data. Objective three (3) of the ongoing research seeks to propose a road maintenance data model based on the maintenance data requirements in the road infrastructure maintenance sector of Uganda. Similarly, research question 3 is accessing the nature of the data used in road maintenance decision making and research question 4 addresses how effectively the data can be represented in a GIS. Because road maintenance data is basically dealing with road condition, which is constantly changing due to several factors affecting the road, this dynamic segmentation data model is obviously unique in addressing road maintenance data requirements. Similar to Mohammad et al, (2009) is Chou et al. (2000)'s implementation of dynamic segmentation for a Pavement Management Information System (PMIS) at the University of Toledo in cooperation with the City of Toledo, in North-western Ohio, United States. Dynamic segmentation in that research was still a necessary tool for the PMIS since it allowed for multiple attributes associated with pavement segments to be stored and displayed efficiently. (Filipov and Davidkov, 2006, and Weigang and Guiyan, 2009) have also performed research on road data modelling.

To relate even more closely with the ongoing research, Ehrensperger et al. (2007) studied the applications of Geographical Information Technologies for Natural Resource Management. They argue that GITs are a prerequisite for natural resource management and a means of spatial analysis. The focus of their research was centred on the potential of Geographic Information Technologies to better inform and involve farmers, communities and governments as well as international panels in planning and negotiation processes. They investigated how these technologies support stakeholders in sustainable-oriented decision-making and the concerns that have to be carefully taken into consideration when using Geographic Information Technologies in developing countries. They discuss the potentials of GITs for various applications ranging from a local to global scale, highlighting issues of integrating knowledge at the local scale, adding spatial dimensions to national development plans, coordinating and monitoring transnational cooperation, assessing global trends as well as formulating strategies. The research is summarized by key issues in GIT implementation. Ehrensperger et al. (2007)'s input on these key issues has a direct relationship with the gaps and challenges that have already been discovered as limiting the GIT implementation in RIM. They include relevance of content, appropriateness of technology, bridging power gaps & digital divides and the institutionalisation of GIT.

Brodnig and Mayer-Schönberger (2000) attempt to stipulate the role of spatial information technologies as a gap bridging mechanism in the integration of traditional (local) environmental knowledge and Western Science. Their efforts are in line with Agenda 21[1]'s chapter on the role and importance of information for sustainable development. Directly they are focussing on the provisions made for harnessing the potential of ICT for strengthening the capacity for traditional information. GITs are specialised ICT tools for collecting, managing and displaying of spatial data. Brodnig and Mayer-Schönberger (2000) acknowledge that the developments in these spatial information technologies cannot be separated from the general trends in ICT. Their field of emphasis is environmental management for sustainable development. They have endeavoured to match various applications in this field with data requirements and appropriate technologies required to bridge these gaps. By comparing the Traditional Ecological Knowledge (TEK) with Western Science (ICT tools), they have concluded that the two should be complementary in order to achieve sustainable development.

A content analysis of 39 articles selected from major GIS and information system publications was made my Croswell (1989). His intention was to assess common problems and approaches for overcoming problems in GIS system implementation activities. He combined this with an examination of other literature plus his own experience in numerous information systems development efforts. With this methodology, he managed to answer the question; what approaches should be taken to increase chances of success and the realisation of the benefits that GIS technology should provide? In this research, in addition to interviews, the approach of reviewing literature to devise strategies of successful GIT implementation is however greatly with stakeholder involvement in order to develop a framework model that can be adopted with limited or no resistance.

Institutionalization of GITs is proposed as a paradigm for studying the impact and effectiveness of GITs by Eric de Man, (2000). (Leitner et al., 1998, Onsrud and Pinto, 1993, Anderson Carrie S., 1996, Goodchild, 2000, Sieber, 2000) all have their publications dealing with some aspects of GITs, either with their adoption, successful implementation or diffusion mechanisms which incline t the basic output expected by the end of this research.

2.3 Concluding Remarks

Majority of the previous research in the area of geo spatial technologies as decision-support tools have focussed on the development of customized GIT models and sys-

1 Agenda 21 is an action plan of the United Nations (UN) related to sustainable development and was an outcome of the United Nations Conference on Environment and Development (UNCED) held in Rio de Janerio, Brazil, in 1992. It is a comprehensive blueprint of action to be taken globally, nationally and locally by organizations of the UN, governments, and major groups in every area in which humans directly affect the environment. (http://en.wikipedia.org/wiki/Agenda_21)

tem applications in several transport divisions. For example, Kumar et al. (2003) in the design of an Intelligent transport system (ITS) using GIS, the avenue programming and scripting language for Arc View GIS3x was used to customize the package, with each script used for a specified purpose (City bus routes, closest facility and shortest path). Also, the applicability of GIS and GPS for asset management of roads and railway transportation, and evaluation of accident black spots on roads in India were all customized researches. In all these attempts, data has been readily availed or, if not, could easily be availed or collected (using the target GITs) for the respective study areas. This research however has its focus on developing a sustainable approach to using geo spatial technologies for road infrastructure maintenance in a situation where data is not readily available and hence an approach needs to be devised to accentuate the acquiring up-to-date data and availing it for better decision making. This is the dilemma facing road infrastructure planners and managers in Uganda. The most immediate problem in Uganda are not models and systems but the capability to utilize GITs for the basics of data collection, management and analysis. Nevertheless, it is appreciated that if data is readily availed, GITs through context specific model developments (as previously discussed in the review) will be more applicable as decision-support tools. Siddeswar (2003)'s illustration of GIT use was specifically targeting traffic monitoring, while, this research is exploring road infrastructure maintenance all falling in the umbrella of road transport management. From El-Shair (2003)'s study, this research has defined yet another case study to Uganda and will in turn affirm the findings that GIS and RS can effectively be used in roads mapping for sustainable decision making.

Within the College of Engineering, Design, Art and Technology (CEDAT) of Makerere University, under the theme, "Sustainable Technological Development in the Lake Victoria Region, Uganda", the research is on the one hand in harmony with Bagampadde (2005)'s investigations of stripping propensity of bituminous mixtures and moisture damage related behaviour of bituminous materials. Bituminous mixture is a material for surfacing roads and the understanding of its chemical behaviour is a prerequisite to its appropriate decision for use. On the other hand, it is related to Musinguzi et al. (2007)'s assessment of GIS data interoperability in Uganda. Musinguzi et al., (2007) discuss the way forward to having GIS data operate flexibly between organisations. It is the norm to have organisations within the same sector managing the same data type (roads network data in this case) but with different structures and semantics. Likewise, this research is dealing with the potential of using GITs to capture road infrastructure maintenance data, particularly condition inventory, which in turn should effectively be used for decision support. Effective use of these data will require resolving concerns of data semantics and interoperability. The key issues to consider on implementation of GITs include appropriate technology specifically the possibility to integrate multi disciplinary data from other utility organisations. These are such aspects that require GIS data interoperability interventions as discussed by (Musinguzi et al., 2007)

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Part 3 - Papers

3.1 Introduction to the papers

Paper I: This paper was published due to the need to create awareness about the current research in the country at the time the AfricaGIS 2009 conference was held in Kampala, Uganda. At that instance, it had already been ascertained that there was a digital divide among the stakeholders involved in the RIM processes. By digital divide here is meant the differences in perception, awareness and understanding of GITs and their potential. The contractor category of stakeholders in RIM was hardly knowledgeable of what GITs were let alone the advantages associated with their usage. In writing this paper, the authors aimed at creating awareness about the research developments under GIT in the country and Africa at large. Considering that the technical professionals employed in the RIM organisations are purely civil engineers this paper served as a disclosure to that bracket of stakeholders of the potential and availability of GITs. The paper gives a background on GITs and discusses the challenges faced by the RIM sector in adoption of these technologies. It proceeds to discuss road management data, particularly road condition spatial data and its inclination to GITs. Considerations of the framework that was then to be developed during the research are also highlighted. A cost effective method of capturing the visual condition of the road is briefly discussed together with the examples of Open Source and Freeware that could support in the display, manipulation and analysis of the captured datasets.

The rest of the papers II, III and IV are a follow up of paper I and addressing sections of the research objectives and questions stated in part one of the thesis.

Paper II: Paper II largely discusses the findings that address objective 1 of the research. It discusses the gaps in the use of GITs in the road infrastructure maintenance process of Uganda and the limitations experienced in accessing these technologies.

Paper III: The focus of paper III is on the algorithmic approach to accentuating the use of GITs in RIM. Since the audience to all the published papers had been somewhat different, it was imperative to give a background to the research. In this background, GITs were introduced; road maintenance data, activities involved and the actors were also briefly discussed. An overview of the gaps and limitations from paper II was similarly made.

Paper IV: This paper is presenting preliminary findings from field measurements in the independent surveying of road inventory and visual condition in the study area. In planning for the fieldwork, the authors had an idea of recommending a cost effective method of capturing road inventory and visual condition data for road maintenance decision support purpose. The plan was to fly over the study area using a low flying paramotor while tracking with a GPS and filming the road with both an ordinary color and a modified consumer camera to measure infrared. The intention was to capture the road shoulders besides the carriageway which ordinarily would not effectively be registered with a RGB camera because of the vegetation interference. However, for safety and security measures, it was not possible to get clearance from CAA, Uganda to affect the flight. Instead, the methodology discussed in the paper was adopted. Suggestions to enhance the findings are mentioned in the discussion within the paper.

PAPER I
GEOINFORMATION TECHNOLOGIES AS DECISION SUPPORT TOOLS IN ROAD INFRASTRUCTURE MAINTENANCE IN UGANDA

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AfricaGIS Conference 2009

ABSTRACT

Road transport in Uganda is by far the most dominant mode of transport. The sector carries well over 90% of passenger and freight traffic. It thus serves as true backbone to support the country's economy. Roads provide the only means of access to most of the rural communities and effective maintenance of this asset is vital to the Government of Uganda's (GoU) strategy for economic development and poverty eradication. It is of recent, that preventive maintenance is being appreciated in Uganda and plans of making it a priority are being put in place. The spatial data, on which Road Infrastructure Maintenance (RIM) actions are based, are not comprehensive enough. However, Geographical Information Technologies (GITs) are known to enable asset management to function in the collection, storage and analysis of data for decision making. This is an ongoing research expected to develop an integral framework for enhancing the use of GITs as decision support tools in the maintenance of roads in Uganda. The paper gives a background on GITs and discusses the challenges faced by the RIM sector in adaption to these technologies. It proceeds to discuss road management data, particularly road condition spatial data and its inclination to GITs. Considerations of the framework to be developed are also highlighted. A cost effective method of obtaining road condition parameters is discussed together with the examples of the freeware used to manipulate the datasets.

Key Words: Road Infrastructure Maintenance, Geographical Information Technologies.

1 BACKGROUND

1.1 Road Infrastructure and Management in Uganda

The transport sector in Uganda consists of four major modes; i.e., air, road, railway and inland water transport. Road transport is by far the most dominant mode of transport within the country, carrying well over 90% of passenger and freight traffic and serving as a true backbone supporting the country's economy Uganda National Roads Authority, Terms of Reference, UNRA-TOR, (2007). Roads provide the only means of access to most of the rural communities making its effective management vital to the Government of Uganda's (GoU) strategy for economic development and poverty eradication. The road transport infrastructure in Uganda comprises about 64,558km of road, including about 10,500km in the National Roads network, 22,300km of District Roads, 2,800km of Urban Roads and 30,000km of Community Access Roads. About 2,200km out of a total of 10,500km of National Roads are bituminized (tarmacked) and the rest are gravel (murram). Government is currently implementing a programme of continuous upgrading of key gravel roads to bitumen standard. These roads are characterized by bad road surfaces, potholes, poor road designs and inadequate road furniture. The government structure of Uganda is composed of 2 tiers, namely Central Government (GoU) and Local Government (LG). The GoU executes its functions through Ministries which receive their mandate from parliament. The Ministry of Works and Transport (MoWT) is responsible for the planning, development and maintenance of the classified road network in Uganda. The LG structure consists of districts governed by autonomous district councils and urban areas governed by autonomous urban councils. The local government act of Uganda was effected in 1997 to decentralize functions, powers and responsibilities, including the devolution of road maintenance services of rural, district, urban and community roads to local and urban authorities. The district and urban authorities are responsible for the maintenance of the district and urban roads respectively. Even though this act allows districts to fully implement routine and periodic maintenance activities, rehabilitation is still handled by the central government through the MoWT. As a further decentralization strategy, the MoWT is planning on issuing out Output Performance - Based Road Contracts (OPRC) where the contractor decides what to do, when to do it, how to do it and where to do it in order to achieve the client prescribed service levels.

1.2 Geo Information Technologies as Decision Support Tools

Geo Information Technologies (GIT) are a set of specialized Information and Communications Technologies (ICT) which help to collect, manage and analyse data about the resources, landscape features, and socio economic characteristics of an area in both space and time (Ehrensperger et al., 2007, Eprensperger et al., 2007). They provide an important feature for communication, dissemination and knowledge sharing on account of their capability to facilitate display and visualise spatial data. GIT includes four basic spatial tools, namely, Geographical Information Systems (GIS), Global Positioning Systems (GPS), Remote Sensing (RS) and web-based tools such as Google earth which provide new ways of sharing information and visualizing near real time data (Ehrensperger et al., 2006, Eprensperger et al., 2007). GIS facilitates storage, management and analysis of geographically referenced data, integrating common database operations with unique means of visualization and the geographic analysis potential of maps. GPS are satellite based positioning systems for capturing locations of sample points such as road junctions, potholes or larger features (land marks) on the road. These landmarks may later be used to reference satellite images or other spatial data layers. Remote Sensing on the other hand is the detecting of the earth's surface from satellites and airplanes by making use of the properties of electromagnetic waves emitted, reflected or diffracted by the sensed objects. It provides images of the earth's surface that can be used to identify especially different types of land cover. Advantages associated with the use of GITs are improved mapping, greater efficiency in retrieval of information, faster and more extensive access to the types of geographical information important to planning, improved analysis, better communication to the public, and speeder access to information for various application processes (Ehrensperger et al., 2007).

(Mazzi, 2007) observed that for the case of Uganda, there is low usability of GITs and spatial data in transport planning. The reasons for low usability of spatial data range from the lack of a data sharing framework between organisations, questionable data quality, absence of data documentation and the absence of clarity in problem definition (in conformity with (Ramasubramanian, 1999)). However, if the right combinations of data algorithms or models are made for a given application, and assurance of data quality is guaranteed the worth of GITs can be achieved. Even though (Hunter et al., 2003) seem to argue that perfect data may be a rarity, the fact remains that there are certain fundamental elements that need to be present in information for it to be considered sufficiently useable for the purposes at hand. The aim of this research is to investigate how Road Infrastructure Maintenance (RIM) managers can exploit the GITs available to them in the collection and use of these relevant data for decision making.

2 RESEARCH CONCEPT

2.1 Problem

Dimitriou and Banjo (1990) have identified road problems in third world countries of which Uganda still faces to date. They include; traffic congestion, high road accidents, weak institutional support leading to poor definition of the problem, and differing technology transfer priorities in problem resolution. In Uganda, several cases of poor transport services are documented in ((Grimaud et al., 2007); (TTCA, 2004); and (Luyimbazi, 2007)). Respectively, these include; the still insufficient transport infrastructure, the poor condition of the northern corridor due to inadequate maintenance and the potholes characterizing most of the roads. Almost all roads in Kampala city are continuously being repaired a consequence of which the city is facing colossal dust, which, besides being an inconvenience to people, is causing several diseases as a result of pollution. The repaired roads hardly last a year before the need for another repair of the same road section. This is largely attributed to impromptu decision making inherent in situations where decision support tools are lacking and pattern matching as well as visual inspection are dominate. The decision on which roads bear maintenance priority has proved to be ad hoc. In many situations roads are upgraded almost immediately after being repaired. However, GITs can go a long way in aiding decision making. Data on the basis of which maintenance decisions are made can be gathered, analysed and updated continuously to allow near real time knowledge of the existing situation of roads. The existing data, on which decisions could be based, are not comprehensive and up to date. It is in this aspect that GITs can be employed to base measures of road maintenance on reliable spatial data.

At the moment, GITs are being underutilized in RIM decision making processes. The desire to use GIS by the MoWT in the management of national and district roads is evidenced by the commissioning of a project known as Management Information Systems (MIS) for district roads in 2006. The MIS was intended to apply GIS for monitoring cross-cutting issues in the Road Sector. To date, it applied mainly for reporting various attributes for road maintenance. The Uganda National Roads Authority (UNRA), an authority charged with the management of national roads, also uses GIS basically for reporting. This research is working towards defining a framework that should enhance the use of GITs particularly towards achieving and managing up-to-date spatial information that will facilitate evidence based decision making in RIM.

2 Research Objectives and Design

The main objective of the research is to develop an integral framework for incorporating GITs as decision support tools in RIM works in Uganda. To achieve this, three specific objectives are defined, 1. To identify gaps in the use of GITs in the RIM process of Uganda and identify the limitations to enhancing the use of these technologies, 2. To develop an algorithmic framework to incorporate GITs as decision support tools in RIM activities in Uganda 3. To develop a data model for road maintenance data basing on the road maintenance data requirements. The study is based in Uganda with Kampala and Jinja as the study areas. RIM is the specific field of study. We are using a multi-method approach which initially involved a thorough identification of all stakeholders in the RIM sector. To ensure synchronization of findings, the data collection methods are cross cutting involving interviews, observations and field measures.

3 DISCUSSION

3.1 GIT Challenges

From the on-going field visits and discussions, five challenges have so far been identified as affecting the use of GIT technologies for data collection in road maintenance. First is the absence of explicit data collection policies. Data collection policies are meant to describe at a high level the type of data to be collected, its frequency and its level of detail. They should also describe the process by which data will be collected, i.e., in house or by contract, the equipment to be used and any other detail that could enhance the use of the data to be collected. Secondly is the previously high costs of satellite images and yet budgets were (and still are) not always availed for data collection. There is a noted digital divide among the stakeholders in RIM. A proposal from management of one organisation for example, is that a technology like remote sensing could assist in the prediction of suitable material resource for pothole fixing such as gravel/ laterite/crash stone which seem to have run out in the country. Management is of the view that remote sensing would reduce on the cost of prostrating considering the high costs of these materials altogether. Another category of stakeholders, the road contractors are at another level of thinking with limited knowledge of the potential of GITs for RIM. Staff are not properly trained and monitored. Remote sensing specialists for example are unavailable in many of these organisations. The data quality assurance procedures are either missing or are inadequate. Similarly, GIS as an already adopted technology within the road management organisations faces challenges of keeping the data current (up to date), implementing standards (data standards) and promoting the sharing of data among agencies (SDI Issues)

3.2 Road Management Data

Road management data is composed of; road inventory, pavement, structures, traffic, finance, activity and resources elements, each of which has various aspects (Paterson & Scullion, 1990). The focus of this research however lies with the network/location aspect of the road inventory element and the pavement condition aspect of the pavement element. The difference between inventory (physical elements of the system) and condition data lies with the fact that inventory data doesn't change remarkably over time. It is typically measured in one off exercises and updated as need arises. Condition data on the other hand changes over time and requires some kind of monitoring (Bennett et al, 2006). During data collection it is always confusing to decide on what data to collect. It is however advisable to; collect only the data that is needed for the present purpose, collect data to the lowest level of detail sufficient to make an appropriate decision, collect data only when they are needed and use pilot studies to test the appropriateness of the approach. According to Bennett et al., (2007) the survey frequency indicates that, inventory data is updated / verified every 5 years and pavement condition data for main roads are collected every 1-2 years, while for minor roads, every 2-5 years. However in Uganda, this is not the case. As mentioned earlier, the roads are in a continuous state of repair and upgrade. This implies that data should always be collected prior to an upgrade or repair schedule in order to prioritize works. The amount, type and detail of the required data should then be the focus during the data collection.

Unless referenced, all these data when collected will be of limited use. There are two elements of reference, the location and the address used to identify the location. The three important components here are 1. the identification of a known point, 2. direction, and 3. distance measurement. The referencing is either linear (measured in kms from a known point) or spatial (measured in latitude and longitude using GPS). In Uganda, the known reference point for linear referencing is the post office located on Kampala road. It is of recent that spatial referencing is being adapted in Uganda. Originally, only GPS locations of the start and end of a road section would be captured. To-date, the UNRA data collection sheets have been designed with an attribute of GPS coordinates for every chainage for which data is collected.

3.3 Framework Development

With the advancement in GITs for spatial data collection and decision making, it is necessary to use some logical construct in form of a framework to define an integration of these technologies in the decision making process of RIM. There are persistent challenges however to integrating institutional and technical solutions to optimize the utilisation of these technologies and the resulting spatial data. In Uganda, the major of these challenges is found to be institutional or political (policy) to be exact. The necessary framework components are in the process of being generated by; assessing the potential of GITs through understanding them thoroughly in terms of their weaknesses, strengths, and requirements for adoption within the RIM discipline; reviewing literature on how new technologies in other disciplines are incorporated into organisations; identifying emerging issues from interviews and field visits and defining methods to address these issues and finally; defining a framework that addresses these issues and proposes inputs. An important point to note however is the non-uniformity of the GIS-Transportation (GIS-T) data models by the different asset management organisations. Dueker and Butler (1999) advocate for a common data model that holds transportation features as the object of interest, and that attributes of transportation features are represented as linear and point events that are located along the feature using linear referencing. This then calls for dynamic segmentation database design for road maintenance data in the responsible organizations.

3.4 Film and Photograph

Road condition data includes mainly road distress surveys which provide information on the various distress types, their locations, severity, and extent (Miller & Bellinger, 2003). These surveys are traditionally based on extensive field observations by trained experts. They evaluate the pavement condition in situ considering a variety of distress types and aggregate the information into a Pavement Condition Index (PCI). This index is a single road performance indicator with a scale usually between 0 and 100 and the higher the value the better the condition of the road. This extensive method of field observations is acknowledged as expensive by, for example, Herold et al., (2004). Their conclusion however was based on a comparison with road condition mapping with hyper spectral image remote sensing. Likewise, we have developed a technique of cost effectively carrying out these distress surveys. This is by filming the road by mounting a video camera onto a vehicle and setting up a GPS logger within the same vehicle. The vehicle moves at a constant speed which together with the width of the road being filmed is recorded. GPS coordinates along sections of the road are registered during the filming. For very evident distresses, photographs are captured with high resolution (13.5 mega pixels) GPS embedded camera. How with this cost effective invention can road / pavement condition parameters be extracted to support the current practice in RIM? The films and photographs of sections of roads in the study area are available for these measurements to be extracted with assistance from a road maintenance expert.

3.4.1. Film and Photograph visualization

It is important to appreciate that besides obtaining the road condition indicators; there is also need for their visualization. There is available freeware that can be used to manipulate the video and photographs to best visualize the road condition indicators needed for decision making.

Routemapper: Routemapper video surveying systems have been used by highway and roll toll authorities in several countries like the UK, Ireland, USA and Canada for various applications. These include; asset management, planning studies and infrastructure placement. Under asset management, it has been possible to measure asset dimensions and export them to external asset management systems and GIS applications. The above mentioned film can be manipulated with routemapper to visualize road condition status and then exported into the GIS application in use. Other interesting features with routemapper are the possibility for integrating video and GIS mapping and the availability of desktop and web application software. The routemapper desktop browser integrates high resolution digital video imagery, accurate location referencing, GIS mapping and data storage into one application. Users can not only digitize and review asset information held in the system, but also load, view and edit many different engineering and GIS based datasets. Client specific network referencing systems can be imported into the software thus allowing users to use a known reference to quickly navigate through the video.

Opticks: Optics is a collection of software tools that enable analysts to develop intelligence products. It generates these products by analyzing signatures and datasets collected from specific technical sensors. These data sets and signatures are presented to the analyst using images and plots. The analyst then uses these views to manipulate the data and run algorithms to generate intelligence products. It is an open source remote sensing application and development framework, supporting traditional imagery, motion imagery, Synthetic Aperture Radar (SAR), multi-spectral and other types of remote sensing data. It supports many remote sensing file formats including ENVI, Generic RAW, ESRI shapefile, MPEG, JPEG, GIF, PNG, BMP, TIFF, GeoTIF. It is also possible to connect to geodatabases with ESRI ArcSDE integration. With opticks one can pan, zoom, rotate, and geo reference spatially large video. For software developers, it also allows for plug-ins.

GeoSetter: GeoSetter is a freeware tool for windows for showing and changing geo data of image files (e.g., images taken by digital cameras). It offers several features like reading picture formats (e.g., JPEG, TIFF as well as camera RAW formats), showing existing geo coordinates and tracks on embedded Google maps. With GeoSetter, it is possible to set geo data by embedded Google maps or by entering known values for coordinates and altitude directly. The disadvantage of using the Google maps is that an internet connection is required which is often a drawback with developing counties where the band width is never guaranteed. It also allows for the synchronization of track files with already geo tagged images (e.g., between RAW images and their corresponding JPEG images). Figure 3-1 shows the main window of the GeoSetter interface and geo tagged photographs of Jinja (Bujagali road) in the display.

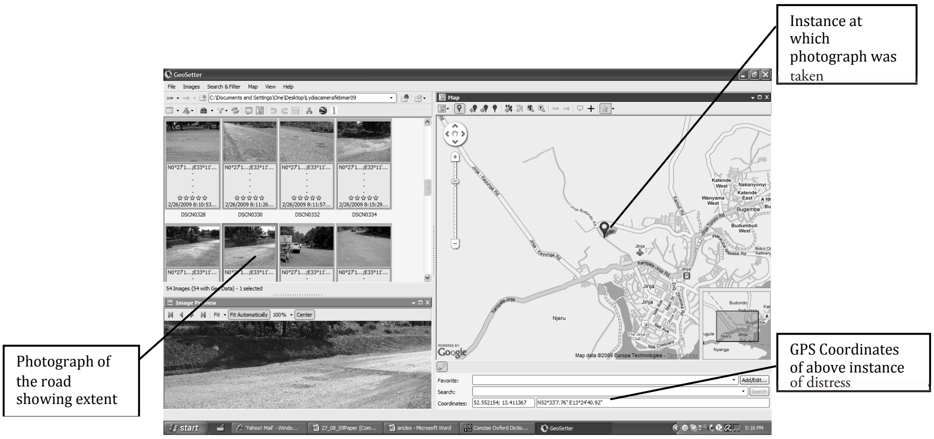

Figure 3-1: A Snapshot of the Geosetter Main Window

4 CONCLUSION

The challenges facing the use of GITs in RIM have been found to primarily relate to knowledge capacity and budgetary issues and the factors limiting their integration are majorly policy related. The data requirements for road maintenance though basically values in terms of indices, visual surveys for inventory and condition would require GIT services. These indices can also be derived from GIT products. Further too, the location reference of both inventory and condition data can only be accurately obtained by use of GITs. The research is working towards recommending a cost effective method of collecting road condition data as it advances towards development of a framework to integrating GITs in RIM. This has progressed by filming the road with ordinary video camera and use of GPS logger that captures GPS coordinates along sections of the road. This coupled with the availability of Open Source and freeware for manipulation of the collected data can go a long way in grounding GITs in RIM. Further exploring of the potential of the GITs and implications of their integration into the decision making process of RIM will have an input into the framework to be developed.

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PAPER II
AN OVERVIEW OF THE GAPS AND LIMITATIONS IN THE UTILIZATION OF GITs FOR ROAD INFRASTRUCTURE MAINTENANCE IN UGANDA

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SUMMARY

This paper is part of ongoing research on the use of Geographical Information Technologies (GITs) as decision support tools in road infrastructure maintenance in Uganda. It discusses the gaps in the use of GITs in the road infrastructure maintenance process of Uganda and the limitations experienced while enhancing the use of these technologies. Road maintenance organizations using GITs are often faced with the need and desire to solve similar and cross-cutting technical problems that are repetitive in nature. However, their current institutional arrangements do not permit forging of lasting partnerships, use of standardized data and operating under a coordinated GIS infrastructure. They also lack standardized fundamental datasets to address key nationwide and local maintenance requirements. Challenges to coordinating how geospatial data are acquired and utilized are the norm in Uganda. Similarly, collection of duplicate data sets at the local and national levels is a common scenario. We finally identify the limitations to accessing GITs in the sector as; lack of infrastructure to support utilization of geographic datasets, unavailability of and limited accessibility to geographic data, limited geospatial capacity at individual and organizational levels and the digital divide. Above all, there are no policies for accessibility and standard use of GITs.

Keywords: Geographical Information Technologies (GITs), Road Infrastructure Maintenance (RIM), Data, Uganda

1. INTRODUCTION

The understanding of geographic technologies, effective use of geographical information and the knowledge of their advantages is critical to the planning and decision making process for asset management departments. A road network and its well being for example are very important for the economic development of the nation. Road Infrastructure Maintenance (RIM) is therefore a prerequisite for the management of roads. Geographic information collected, managed and analyzed using Geographical Information Technologies (GITs) is very useful in decision making for RIM. GITs are commonly referred to as ICT tools used in the collection, management, maintenance, manipulation and presentation of geographic data and or information (Ehrensperger et al., 2007). The use of these technologies is known to simplify decision making to a non technical level and to support the stakeholders in sustainable-oriented decision making. However, these technologies are underutilized for RIM in Uganda.

Uganda is beyond the first appearances of GIT, when only highly qualified professionals could handle them. Today, advances in technology are tremendous (Ehrensperger et al., 2007). A wide range of GIS is available ranging from high cost server based to low cost user-friendly desktop software. The sector has noted the increase in the availability of spatial data. The spatial and temporal resolution of remote sensing data has impressively increased, and more data are now freely available. The most outstanding advancement has probably been the development of the internet and web GIS which have opened up new opportunities such as access to real time maps, cheap and frequent data updates and worldwide sharing of spatial information. Through graphic representation and spatial analysis, the use of GITs helps to make RIM processes understandable to decision makers and lay persons (Ehrensperger et al., 2007).

Use of GITs is increasingly shifting from reference tools to dynamic decision making tools. This shift has been triggered by, among other factors, emergency situations such as the World Trade Centre (WTC) attacks of September 11 200l (Teresa M. Harrison et al., 2007). This attack became a catalyst for change in the use of GITs for almost all relevant disciplines transportation inclusive. This paper outlines the RIM organization in Uganda, the actors involved as well as their roles. It discusses the gaps that have been identified in the use of GITs for RIM in Uganda and the limitations associated with enforcing the use of these technologies.

2. GEOGRAPHICAL INFORMATION TECHNOLOGIES - THE PROBLEM

Geo Information Technologies (GIT) are a set of specialized Information and Communications Technologies (ICT) which help to collect, manage and analyse data about the resources, landscape features, and socio economic characteristics of an area in both space and time (Ehrensperger et al., 2007). They provide an important feature for communication, dissemination and knowledge sharing on account of their capability to facilitate display and visualise spatial data. More recently, it has become clear that GIS, together with Global positioning systems (GPS), aerial photography, remote sensing techniques, and other spatially related tools for decision making, comprise a larger array of complementary tools that can be grouped together under the more comprehensive rubric of “geographic information technologies” (GIT) (Teresa M. Harrison et al., 2007). According to Ehrensperger et al. (2007), GIT include four basic spatial tools, namely, Geographical Information Systems (GIS), Global Positioning Systems (GPS), Remote Sensing (RS) and web-based tools such as Google earth which provide new ways of sharing information and visualizing near real time data. GIS facilitates storage, management and analysis of geographically referenced data, integrating common database operations with unique means of visualization and the geographic analysis potential of maps. GPS are satellite based positioning systems for capturing locations of sample points such as road junctions, potholes or larger features (land marks) on the road. These landmarks may later be used to reference satellite images or other spatial data layers. Remote Sensing on the other hand is the detecting of the earth's surface from satellites and airplanes by making use of the properties of electromagnetic waves emitted, reflected or diffracted by the sensed objects. It provides images of the earth's surface that can be used to identify especially different types of land cover. The advantages associated with the use of GITs include; improved mapping, greater efficiency in retrieval of information, faster and more extensive access to the types of geographical information important to planning, improved analysis, better communication to the public, and faster access to information for various application processes (Ehrensperger, 2006). Uganda has not fully benefited from the above advantages and as Mazzi (2007) observed, this manifested in under utilization of GITs and spatial data in transport planning. However, it is important to note that efforts are now emerging to take advantage of the benefits of GITs. The desire to use GIS by the Ministry of Works and Transport (MoWT) in the management of national and district roads as evidenced by the commissioning of a project known as Management Information Systems (MIS) for district roads in 2006 is one of such efforts. The MIS was intended to apply GIS for monitoring cross-cutting issues such as gender, occupational health, HIV/Aids and environment in the Road Sector. To date, the MIS is still being applied mainly for capturing and reporting various attributes for road maintenance. Similarly, the Uganda National Roads Authority (UNRA), an authority charged with the management of national roads, also uses GIS primarily for reporting purposes. Whereas it is the desire of UNRA and other institutions to utilize GIS in their activities, there is a general requirement that limits utilization of GITs. The limitation essentially originates from the inherent nature of GITs. The use of GITs rests on the ability to access core data sets and uniform or interoperable spatial reference system that can serve as foundation for the development of subsequent applications that depend on sharing geospatial information across regions and integrating geospatial information with other relevant data sets (Wehn de Montalvo, 2002) as cited by (Teresa M. Harrison et al., 2007). The major problem therefore is the underutilization of GITs in the Road Infrastructure Maintenance process of Uganda. The main objective is to identify the gaps in the use of GITs and limitations to enforcing their use for RIM in Uganda.

3. METHODOLOGY

This study covered Kampala and Jinja districts as the study area, see figure 3-2. The project adopted a multi-faceted approach. In this approach, the initial stage involved the identification of all stakeholders / actors in the road infrastructure maintenance sector. This was followed by a review of documentation describing the road maintenance process. Key informant interviews using an interview guide were conducted with the road engineers, managers and GIS specialists in the identified organizations. Furthermore, other knowledgeable personnel involved in the road maintenance activities were also interviewed. In summary, a combination of expert and snowball sampling techniques were used to identify persons with knowledge and demonstrable experience and expertise in GITs. The sampling frame comprised of managers in road maintenance organisations and departments and the sample size was limited to 3 persons per organization. The result was that a total of 23 persons were interviewed across all the organisations. In addition to the above methods, participant observations and field measures were triangularly employed to ensure complimentarily of findings. Finally, an independent mapping of the roads as a check to the existing geo databases was done.

From a combination of interviews, document review and other techniques as outlined above, gaps in the use of GITs were derived. Later on during the participant observation and field measure phases, these gaps were confirmed and this served as a basis for deriving limitations to enhancing their use. To understand the nature of the identified gaps and limitations further, it was considered necessary to evaluate the organizations and their processes. For this purpose therefore, more data pertaining to the following institutional aspects was collected; the organizational structure of RIM component, activities undertaken in the maintenance process, actors involved in these activities, the goals and regulations that govern the activities, and the documents that are created during the maintenance process. The findings are documented in the following sections of the paper.

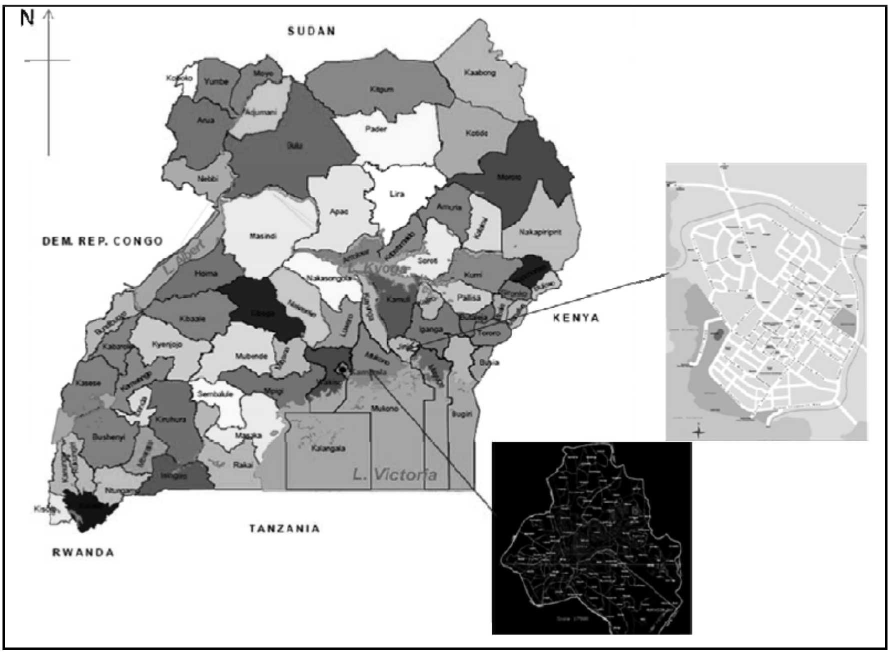

Figure 3-2: Map of Uganda Showing Kampala and Jinja Areas

4. FINDINGS

4.1 Road maintenance Activities and Actors

The Ministry of Works and Transport (MoWT), Uganda National Roads Authority (UNRA), consultants and contractors were identified as the key stakeholders in Road Infrastructure Maintenance (RIM).Local governments and donors also play a part in some circumstances. MoWT has the constitutional mandate to set policy, regulate, set standards, and provide technical guidance and monitoring to the construction industry. Uganda's road network comprises about 78,000 km of road of which 21,000 km are national, 22,500 km are district, 4,500 km are urban and 30,000 km community access roads. The Uganda National Roads Authority is responsible for development and maintenance of national roads. The district and urban authorities are responsible for construction and maintenance of the district and urban roads respectively. All districts are staffed with engineers, planners and surveyors. In Kampala for example, Kampala City Council (KCC), a local government organization, is charged with the responsibility of maintaining district roads within the city. Depending on the size of road and the scope of works required, KCC normally decides whether or not to perform maintenance works using in house equipment and personnel or contract based road maintenance. In the latter method, a private contractor is often procured and hired to perform the works under direct or indirect supervision by KCC. Under indirect supervision, a private consultant company is assigned supervisory role on behalf of the client and this normally depends on the project size and availability of funds. The community access roads are a responsibility of the lower local governments and their maintenance is often community based.

4.2 Gaps in GIT utilization

The gaps and limitations to using GITs in RIM have been based on one guiding principle that organizational stand alone GIT usage is costly and time wasting. On the basis of this principle, the gaps identified have been grouped in four basic categories as discussed in the following section.

(i) *GITs are not integrated into the working procedures of any of the involved organizations*. In order to build up the capacity and infrastructure in GITs, their use has to be incorporated in the ongoing practices of the organizations. The sustainability of GIT usage will be derived from their frequent use for planning, reporting and decision making of the routine and periodic maintenance activities. However, it is observed that GIT usage is on project basis and convenience. KCC for example is tasked with the responsibility of maintaining the roads within Kampala, however, the GIS data available with KCC to-date were obtained during the capacity building project in 2003. These have not been updated since then. Similarly, the use of satellite imagery by consultants is on project basis. All of the projects that use imagery have the specifications stipulated in the terms of reference and this ends at project level. However, there is an ongoing consultancy "Road Inventory Study" whose principal objective is to assist UNRA to establish a National Roads Databank and Asset Management System. These are to be used as a decision-making support tool for annual and multi-annual maintenance and investment work plans and reporting on road and bridges in the country. The future sustainability of the system is fundamental and the strategy adopted by the consultant during the assignment is therefore directed at this objective. As such training of the client's staff and technology transfer are important, Uganda National Roads Authority Terms of Reference (UNRA-TOR, 2007).

(ii) *The current institutional arrangements are not inclined to lasting partnerships, standardized data and a coordinated GIS infrastructure.* As observed from the organizational structure of the RIM process, the organizations involved are not standalone. For instance, in one project the contractor reports to the consultant who also reports to UNRA who then finally reports to the ministry- MoWT. However, this workflow is often organized for a particular project on an ad-hoc basis. In case the same consultant and contractor are to work together on another project, a different institutional arrangement may be defined. Once processes and institutional arrangements change as a result of changes in project reporting arrangements, the data format and standards change. Considering that these involved organizations use similar datasets in resolving routine and periodic maintenance problems, it is a requirement that these datasets are standardized and that the relationship between the organizations is formal. In essence, it has become difficult to archive these data in a coordinated GIS infrastructure for RIM.

(iii) *Lack of data sharing and collaboration.* The emphasis on technical rather than institutional and data-related issues was earmarked by (Martin Ralphs and Wyatt, 1998) as one of the common problems that GIS applications encounter. Data sharing and collaboration is vital in avoiding duplication of efforts for the organizations involved in RIM. There is a number of fundamental datasets used in all GIS projects. Most of the data used in the management of such projects is shared among utility disciplines. These include water, power, telephone lines, land use, etc. However, there is lack of collaboration among the utility companies. Majority of the utility companies (NWSC, UEB, UMEME) for example have established GIS units through which collaboration would benefit the road sector and further the establishment of its GIS unit. The United States General Accounting Office (GAO, 2003) argues that long standing challenges to data sharing and integration need to be addressed before the benefits of geographic information systems can be fully realized. The problems leading to this gap have been identified to include; insufficient knowledge of who owns what data and the status of the data, differences in reference frames, data pricing irregularities, copyright and privacy policies, data quality aspects and technological issues related to incompatibility of software platforms. However, collaboration has been proved to allow for the pooling of resources and better use of synergies (Ehrensperger et al., 2007). This in turns leads to motivation among the technical staff as tasks become more diversified and interesting.

(iv) *There is lack of a data foundation to address key national and local maintenance requirements*. Initiatives for establishing a Spatial Data Infrastructure (SDI) - a framework for connecting all users of Geographical Information (GI) to the producers (or data) through an efficient infrastructure (Nebert, 2004) are not forthcoming in

Uganda. In Washington, Update (2001), recognizes a similar gap which is stated as the lack of a common data foundation to address key state-wide and local policy issues. This in turn has been found to deprive the organizations of geospatial data. It is widely recognized that collecting data multiple times for the same purpose is wasteful and inefficient. Geospatial data collected to meet the requirements of district roads for example is useful to UNRA in the management of national roads. This is basically because some sections of national roads qualify as district roads. However, the use of these data for the two parties is only possible if the data meet a set of basic and consistent guidelines and protocols. In turn, this will require the existence of policies and standards governing data collection and management.

4.3. Limitations in GIT usage

Basing on the same principle highlighted above, the limitations to enforcing the utilization of GITs in RIM have been categorized into five categories as discussed below.

(i) *Absence of policy on the standard use of GITs*: One of the principal inputs for effective road management is well defined objectives such as would be stated in a policy framework. Usually, policies provide guidelines of use and set forth the principles that govern the use of the set technology. Absence of a policy that encourages the use of GITs in RIM and sets forth the standards to be followed is a fundamental limitation. 100% of the road contractors for instance argue that they have no reason to invest in GIT applications if their use has not been set as mandatory.

(ii) *Budget Limitations:* Besides the costs of equipment and data collection, building GIT capacity and infrastructure also require a predefined budget. Lack of durability of GIT based projects is often due to insufficient budgets for the involved activities. It has been the tradition that budgets and programs for road works in Uganda have been prepared on a historical basis. This implies that each year's budget is based upon the previous year with an adjustment for inflation. It is a requirement that budgets be prepared basing on objective needs-based approaches to incorporate knowledge of the content, structure and condition of the roads being managed. The GIS project in KCC in 2003 is still referred to today for its premature ending with no benefit realization simply due to budgetary limitations. Just like any other technology, GIT usage requires ongoing improved capacity to handle the fast growing technology. This too requires a budget for training the responsible professionals. Even though satellite imagery is freely available to-date, the images face a challenge of being old. The up to date imagery is quite costly to be procured by the organizations. Likewise, the initial capital for GIS establishment is quite high even though the operational costs are manageable. All the contractors interviewed made it clear that their revenue is not worth the investment in these technologies.

(iii) *Lack of infrastructure to support use of geographic datasets*: Effective use of geographic data requires that these data are collected, maintained and updated on a regular basis. Decision making for transport maintenance requires access to data from multiple sources. To this effect, sister organizations using similar datasets should be in a position to share these data when needed. The universally accepted frameworks for geographic data management in Uganda are still under developed. Data structures, formats, syntax, and terminology, which constitute semantic content or quality standards, do not exist. This coincides with National et al. (2002) and Kitty Hancock and Fletcher (2004) that there is no universally accepted framework for geographic data management in Africa. The acceptable infrastructure requires efficient telecommunication infrastructures. At the moment, access to geographic data through the internet is limited as high connection cost and low bandwidth restrict data sharing

(iv) *Geospatial capacity at individual, organizational and societal levels:* The professionals that work in the field of road maintenance have diverse responsibilities. However, the ministry has a department that is responsible for planning, designing, constructing, and maintaining the transportation infrastructure. The professionals charged with this task are majorly civil engineers, trained in the areas of design and construction. As a result, challenges to coordinating how geospatial data are acquired and used are the norm. Collecting duplicate data sets, at the local and national levels is a common scenario. However, parameters related to the inventory and condition of roads requires an input from geographic data. Decisions to repair given roads are dependent on them. This then requires that GIT professionals are thus a necessity in the said department. However, in this case, these professionals are availed on project basis. This usually creates a gap at the close of the project living a lot to be desired.

(v) *Digital divide*: The implementation of GITs and the related data conversion across the country is still uneven. The government organizations (MoWT, UNRA and KCC – Local Government) unlike private companies (the contractors and consultants)' are 'richer', often donor funded. They are fast growing and experiencing a rapidly increasing demand for services. They are therefore often able to afford the funds to support the development of robust GITs. The consultant and contractor communities change more slowly and generate less revenue. The significant upfront costs of staffing and implementing GITs (satellite imagery, data conversion, hardware & software, training, etc) have impeded the adoption of these more efficient and productive computerized systems in this category of stakeholders. This has resulted into the continued use of manual and hardcopy methods and materials in most of the spatial applications of these organizations. This we refer to as the digital divide between UNRA, the Ministry and the Local Government and the contractors and consultants.

5. CONCLUSION

The paper has discussed the gaps in the use and limitations to accessing GITs for RIM. These have so far been found to be both social and technical in nature. The gaps in using these technologies include; the lack of an integration of GITs in the organizations' working procedures, inadequate institutional arrangement that should allow for lasting partnerships, absence of standards for data and a coordinated GIS infrastructure, absence of data sharing and collaboration and the lack of a data foundation at national and local levels. The limitations to accessing GITs in RIM include; the absence of a policy on standard use of GITs, budget constraints, inadequate geospatial capacity at all levels and the digital divide between the involved organizations. Apparently, research in the road maintenance sector is yet to tackle various ways in which GITs can be used to further their performance as decision support tools. A proposal for a rational algorithmic incorporation of GITs in RIM in Uganda will be presented at the 2nd Advanced Engineering Technologies' (AET) conference in February 2010 in Kampala, Uganda.

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PAPER III
ALGORITHMIC INCORPORATION OF GEOGRAPHICAL INFORMATION TECHNOLOGIES IN ROAD INFRASTRUCTURE MAINTENANCE IN UGANDA

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ABSTRACT

Geographical Information Technologies (GITs) are underutilized for Road Infrastructure Maintenance (RIM) in Uganda, thus the necessity to rationally incorporate their use as decision support tools in the participating organizations. GITs herein include Remote Sensing, Global Positioning Systems (GPS), Geographical Information Systems (GIS) and web based tools such as Google earth. This paper is rooted in research undertaken to assess the use of GITs as decision support tools in RIM in Uganda. Basing on results from interviews, field visits & measures and participant observations, the gaps and limitations to the usage of GITs for RIM in Uganda are briefly discussed. The data requirements for RIM are highlighted. The paper suggests an algorithmic approach to accentuate the usage of GITs in the RIM process. This approach involves: a policy on data collection guidelines emphasizing the use of GPS, satellite imagery and GIS, capacity building in the benefits of using GITs and the science involved, establishment of a local spatial data infrastructure for road maintenance and setting aside yearly budgets for the defined activities. The dynamic segmentation data model is identified as a superior data storage strategy for road maintenance data within the GIS.

Keywords: Geographical Information Systems (GIS), Geographical Information Technologies (GITs), Road infrastructure Maintenance (RIM), Uganda

1 INTRODUCTION

The understanding of Geographic Information Technologies (GITs), effective use of geographical information and the knowledge of their advantages is critical to the planning and decision making processes for asset management departments. A well maintained road network asset is very important for the economic development of the nation. Therefore, Road Infrastructure Maintenance (RIM) is a prerequisite for the management of roads. The use of Geographic Information (GI) that is collected, managed and analyzed using GITs is very useful in decision making for RIM. GITs are commonly referred to as Information Communication Technology (ICT) tools used in the collection, management, maintenance, manipulation and presentation of geographic data and or information (Ehrensperger et al., 2007). The use of these technologies is known to simplify decision making to a non technical level and to support the stakeholders in sustainable-oriented decision making. Embracing and continuing to develop a flexible, methodological framework for the integration of decision-supporting technologies with infrastructure is fundamental to supporting effective incorporation of spatial data in decision-making (Cartright, 1993). However, GITs in Uganda are underutilized. There is no comprehensive methodology or framework for addressing both the technical and non-technical issues affecting GIT implementation. This paper highlights data requirements for RIM, the organization of the RIM process and the gaps and limitations in utilization of GITs in RIM in Uganda. Finally, it suggests an algorithmic approach in form of a framework to accentuate the use of GITs in RIM.

2 METHOD

This study covers Kampala and Jinja districts as the study area. It adopted a multi-faceted approach. In this approach, the initial stage involved the identification of all stakeholders / actors in the road infrastructure maintenance sector. This was followed by a review of documentation describing the road maintenance process. Key informant interviews using an interview guide were conducted with the road engineers, managers and GIS specialists in the identified organizations. Furthermore, other knowledgeable personnel involved in the road maintenance activities were also interviewed. In summary, a combination of expert and snowball sampling techniques were used to identify persons with knowledge and demonstrable experience and expertise in GITs. The sampling frame comprised of managers in road maintenance organisations. The sample size was limited to 3 persons per organization and the result was that a total of 23 persons were interviewed across all the organisations. In addition to the above methods, participant observations and field measurements were triangularly employed to ensure complimentarily of findings. Finally, an independent mapping of the roads as a check to the existing geo databases was done. From a combination of interviews, document review and other techniques as outlined above, gaps in the use of GITs were derived. Later on during the participant observation and field measurement phases, these gaps were confirmed and this served as a basis for deriving limitations to enhancing their use.

3 ROAD MAINTENANCE ACTIVITIES AND ACTORS

The key stakeholders in the RIM process are; The Ministry of Works and Transport (MoWT), Uganda National Roads Authority (UNRA), consultants and contractors. Local governments and donors also play a part in some circumstances as outlined below. The Ministry of Works and Transport (MoWT) has the constitutional mandate to set policy, regulate, set standards, and provide technical guidance and monitoring to the construction industry. The Uganda National Roads Authority (UNRA) is responsible for development and maintenance of national roads. The district and urban authorities are responsible for construction and maintenance of the district and urban roads respectively. All districts are staffed with engineers, planners and surveyors. In Kampala for example, Kampala City Council (KCC), a local government organization, is charged with the responsibility of maintaining district roads within the city. Depending on the size of road and the scope of works required, KCC normally decides whether or not to perform maintenance works using in house equipment and personnel or engage contract based road maintenance. In the latter method, a private contractor is often procured and hired to perform the works under direct or indirect supervision by KCC. Under indirect supervision, a private consultant company is assigned supervisory role on behalf of the client (KCC in this case) and this normally depends on the project size and availability of funds. The community access roads are a responsibility of the lower local governments and their maintenance is often community based.

4 ROAD MAINTENANCE DATA

Road management data is composed of; road inventory, pavement, structures, traffic, finance, activity and resources elements, each of which has various aspects (Paterson and Scullion, 1990). Table 3-1 shows the composition of road management data grouped in elements and data aspects of each element. The focus of this research however lies with the spatial data relating to the network/location and pavement condition aspects of the road inventory and pavement elements respectively. The difference between inventory (physical elements of the system) and condition data lies with the fact that inventory data doesn't change remarkably over time. It is typically measured in one off exercises and updated as need arises. Condition data on the other hand changes over time and requires some kind of monitoring (Bennett et al, 2006).

Table 3-1: Elements of Road Management

Element	Aspects
Road inventory	Network / Location, Geometry
Pavement	Pavement structure, Pavement condition
Structures	Structures inventory, Bridge condition
Traffic	Volume, Loadings, Accidents
Finance	Unit Costs, Budget, Revenue
Activity	Projects, Interventions, Commitments
Resources	Institutional, Materials, Equipment

Source: Paterson and Scullion (1990)

GITs are capable of effectively monitoring these untimely changes. According to Bennett et al., (2007) the survey frequency indicates that, inventory data should be verified every 5 years and pavement condition data for main roads should be collected every 1-2 years. For minor roads however, survey frequency should be every 2-5 years. However, in Uganda, this is not the case. The roads are in a continuous state of uncoordinated repair and upgrade. This implies that data should always be collected prior to an upgrade or repair schedule in order to prioritize works. The amount, type and detail of the required data should then be the focus during the data collection.

5 GAPS AND LIMITATIONS IN GIT USAGE IN RIM

The gaps and limitations in GIT utilization are based on one guiding principle that organizational stand alone GIT usage is costly and time wasting. In consequence, these gaps and limitations are categorized into 4 and 5 groups respectively.

5.1 Gaps in GIT Utilization

5.1.1 GITs are not integrated into the working procedures of any of the involved organizations: It is observed that GIT usage is on project basis and convenience. In order to build up the capacity and infrastructure in GITs however, their use has to be incorporated in the ongoing practices of the organizations. The sustainability of GIT usage will be derived from their continued use for planning, reporting and decision making of the routine and periodic maintenance activities.

5.1.2 The current institutional arrangements are not inclined to lasting partnerships, standardized data and a coordinated GIS infrastructure: From the current organizational structure, the stakeholders in the RIM process are not stand alone. Despite this, their workflow is organized on project basis in an ad-hoc way. Once processes and institutional arrangements change as a result of changes in project reporting arrangements, the data format and standards change. In essence, it is increasingly becoming difficult to archive these data in a coordinated GIS infrastructure for RIM.

5.1.3 Lack of data sharing and collaboration: The problems leading to this gap have been identified to include; insufficient knowledge of who owns what data and the status of the data, differences in reference frames, data pricing irregularities, copyright and privacy policies, data quality aspects and technological issues related to incompatibility of software platforms, also in harmony with Musinguzi et al., 2007 and Mazzi, 2007.

5.1.4 There is lack of a data foundation to address key national and local maintenance requirements: Initiatives for establishing a Spatial Data Infrastructure (SDI) - a framework for connecting all users of Geographical Information (GI) to the producers (or data) through an efficient infrastructure (Nebert, 2004) are still not forthcoming in Uganda (Musinguzi et al., 2007).

5.2 Limitations in GIT usage

5.2.1 Absence of policy on the standard use of GITs: One of the principal inputs for effective road management are well defined objectives such as would be stated in a policy framework (Robinson, 1998, Paterson and Scullion, 1990). However, there is no such policy that encourages the use and sets forth the standards to be followed in the use of GITs in RIM.

5.2.2 Budget Limitations: It has been the tradition that budgets and programs for road works in Uganda are prepared on a historical basis. This implies that each year's budget is based upon the previous year with an adjustment for inflation. Lack of durability of GIT based projects is often due to insufficient budgets for the involved activities. Besides the costs of equipment and data collection, building GIT capacity and infrastructure also require a predefined budget with a more long term perspective for non-annual investments.

5.2.3 Lack of infrastructure to support use of geographic datasets: The universally accepted frameworks for geographic data management in Uganda are still underdeveloped. Data structures, formats, syntax, and terminology, which constitute semantic content or quality standards, do not exist. An acceptable geographic data infrastructure requires efficient telecommunication infrastructures. At the moment, access to geographic data through the Internet is limited and high connection cost and low bandwidth restricts data sharing on a national level in Uganda.

5.2.4 Geospatial capacity at individual, organizational and societal levels: The professionals that work in the field of road maintenance are majorly civil engineers, trained in the areas of design and construction. As a result, challenges with the acquisition and coordination of geospatial data are far too common.

5.2.5 Digital divide: The implementation of GITs and the related data conversion across the country is still uneven. The government organizations (MoWT, UNRA and KCC – Local Government) unlike private companies (the contractors and consultants) are often donor funded. They are therefore often able to afford the funds to support the development of robust GITs. The consultant and contractor communities change more slowly and generate less revenue. The significant upfront costs of staffing and implementing GITs have impeded the adoption of these more efficient and productive systems in this category of stakeholders.

6 ALGORITHMIC ACCENTUATION OF GIT USAGE IN RIM

The algorithmic approach proposed is an operational framework within which the road maintenance sector could accentuate the use of GIT in RIM. It is not sequential but iterative in the sense that the outlined strategies depend on and support each other as discussed in the following sections. This therefore qualifies it as a nondeterministic algorithm.

6.1 Policy on GIT usage for RIM

The setting up of a policy on the obligatory use of GITs by all stakeholders in RIM could be the first step towards enhancing the use of the mentioned technologies. Support structures do not emerge and do not continue to exist automatically. They need political commitment (Yeh, 1991, Sundeep Sahay and Walsham, 1996, Heather Campbell and Masser, 1995). This political commitment should be in form of policies. The policy could state data collection guidelines emphasizing the use of GPS, aerial photographs, satellite imagery and GIS. In the long run, GITs in self could be used in routine support of policy making. Even though GIT projects have ended up in frustration for the organisations involved, it is advisable that the whole conception begins with a similar setting which at the moment is working well for UNRA under the project of setting up a National Road's data bank. Mandatory project requirement for the institutionalization of GITs is advocated for by Eric de Man (2000). The use of consultants to guide or participate in feasibility study is recommended (Onsrud Harlan J and Pinto Jeffrey K, 1991). The use of consultants is desirable to review organizational goals, assess needs, offer alternatives, and develop strategy.

6.2 Capacity building in GITs

With a policy in place, capacity building on the benefits of using GITs and the science involved would then be necessary. In the present study, it has been observed that, the contractor category of the involved stakeholders has limited knowledgeable of the benefits of GITs let alone the functionalities of the technologies themselves. Capacity building for this category of stakeholders could begin with diffusion "the process of communication of an innovation to and among the population of potential users with an aim of them adopting it" Zaltman et al, 1973 in (Onsrud Harlan J and Pinto Jeffrey K, 1991). The capacity building could then proceed as follows;

6.2.1 Continued Professional Development (CPD): CPD should become an integral part of the processes of enhancing geospatial capacity in RIM. Organizations that provide professional training on geographic information sciences such as universities, and private companies should be strengthened and linked to the organisations in RIM-a move towards the triple helix concept of government, academia and industry working together for sustainable development. This definitely requires a budget as will be discussed in the section 6.5.

6.2.2 University collaboration: Public universities should initially become a focus for capacity building including training and research in GITs. In due course, private universities with the means could partner with the participating organizations as well. The stakeholders' organizations – the Ministry in this case should coordinate the efforts of these universities to achieve this goal. Basing on the will be advancement of GIT usage in the sector, a recommendation of priorities for research should be made by the stakeholders. More so, these universities should be included in the various data management and usage networks, which are a step towards the establishment of a Local Spatial Data Infrastructure (LSDI) for the sector (see section 6.3). The evaluation of curriculum design and content should be an ongoing activity basing on the advancement of GIT usage in the sector. According to (Ghose, 2001, Leitner et al., 1998, Helga Leitner et al., 2000, Leitner et al., 2000), university partnerships are deemed advantageous in several respects including easier access to the rich potential sources of GIS expertise at the university. The ability to focus on the specific data and application needs of the partnering organization and the lower costs of learning and maintaining the GIT system will in due course be realized.

6.2.3 Systematic Research: Adopt systematic research on factors and processes affecting the diffusion, utilization and impact assessment of GITs by considering the variety of conceptual and methodological problems (Onsrud Harlan J and Pinto Jeffrey K, 1991). The observed digital divide will eventually be addressed in the process of attending to the research recommendations.

6.3 Establishment of a LSDI for road maintenance data

Sustainable management of the road infrastructure calls for the integration of stakeholders from different decision making levels in planning. The use of spatial information management tools will in this case support multi stakeholder and the multi level approaches in the road maintenance field. Therefore, by starting from local perspectives and knowledge, and subsequently integrating external views, multi- stakeholder approaches should be used for the problem definition and priority setting stages of any project. The establishment of a LSDI is proposed for the above reasons. A spatial data infrastructure (SDI) is a framework of spatial data, metadata, users and tools that are interactively connected in order to use spatial data in an efficient and flexible way. Local in the sense that it is specific for the RIM sector as the country subsequently integrates external views into a National SDI.

6.4 Promoting collaboration and data sharing amongst the stakeholder organizations

Like all technologies, GITs encompass technical and non technical issues (Eric de Man, 2000). It is therefore important to realize that success is not necessarily guaranteed by a perfect technical tool (Anderson Carrie S., 1996) but also by addressing the social aspects that require collaboration between organizations. In promoting organizational cooperation, emphasis should be placed on fostering innovation and the transfer of geographic data and technology through; 1. Partnerships and research networks among government agencies, research and training institutions, the private sector and the non government sector and 2. Advocating for international collaboration and cooperation between developed and developing countries

6.5 Setting aside yearly budgets for the defined activities

A crucial aspect of successful GIT implementation is accessibility which includes costs of hardware, software and data (Ehrensperger et al., 2007). It is advised that funding opportunities are identified and the government organisations, the Ministry and UNRA in this case, aggressively pursue application for those monies. This should be with particular emphasis on addressing digital divide issues and framework priorities. For sustainability, the usage of GITs should be integrated into the working procedures and budgets of all the involved organisations in RIM.

6.6 Adoption of the dynamic segmentation data model

There is no existing data model used for the GIS-T (GIS for Transportation) in Uganda. The traditional arc node relational data structure is used to maintain data within the GIS. However, the dynamic segmentation (DynSeg) data model is considered a superior data storage strategy within the GIS-T. DynSeg is the process of transforming linearly referenced data (also known as events) that have been stored in a table, into features that can be displayed, queried and analyzed on the map (Jelokhani-Niaraki et al., 2009) through computations. It is widely used in GIS-T as an efficient measure to manage the heterogeneous attributes along the roads without any redundant data storage (Eddie Y. et al., 2002). This in turn allows for less storage space, quicker data processing, and more information storage. The usefulness of road maintenance data can be greatly enhanced by applying a segmentation procedure to produce sections that are uniform and consistent with the road condition.

7 CONCLUSION

The paper has discussed the road maintenance organization in Uganda, the data required for road maintenance, and the gaps and limitations to using GITs in the RIM process. It has in turn suggested a framework through which the RIM sector would enhance the use of GITs for road maintenance. This framework is not linear but iterative since all strategies discussed are dependent and supportive of each other. The standard requirements which comprise a successful institutional GIT model include; drafted and passed policies allowing for long term upper management commitment to the GIT projects, sufficient allocation of resources, adequate staffing in terms of numbers and skills/ competencies, timely and sufficient training and organizational communication to smoothen the transition to full utilization. On the adoption of an institutional GIT model, it is recommended to develop effective frameworks for evaluating the utilization of GITs. These frameworks are critical to the long term efficacy of GITs .

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PAPER IV
LOW COST GIT BASED TECHNOLOGY FOR PRELIMINARY ROAD MAINTENANCE DECISION SUPPORT

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ABSTRACT

This paper presents a low cost GIT based data collection technology that is similar to the ROad Maintenance Data Acquisition System (ROMDAS). It is composed of a vehicle, two digital video cameras, 2 GPS receivers and a notebook computer. Two different camcorders used for comparison purposes (one real color and the other a modified consumer camera to register infrared) are mounted at the front of the vehicle using a homemade gyro mounting. The GPS receivers are placed at the dash board of the vehicle. The notebook computer and GPS receivers are configured to record the position of the vehicle as it moves. The GPS log files maintain recordings of the latitude, longitude, time, speed and altitude of the vehicle position, as the researcher annotates a map document in the ArcGIS 9.3 software with location referencing details and various road attributes. This data collection technology is aimed at exposing the potential of GIT technology in performing inventory of the road condition. The captured data may be useful for a variety of applications relevant to road inventory and maintenance. It is basically recommended for preliminary road maintenance diagnosis for which in depth road section analysis may proceed for the affected road sections. With this technology, it is possible to map road marks and other architecture along the road and provide a map immediately by the end of the survey. In conclusion, data mining of the spatial video databases to facilitate routine and periodic maintenance decisions and the possibility to modify consumer cameras for research purposes is recommended.

Keywords: Geographical Information Technologies (GIT), road maintenance, video-log, ROMDAS

1 INTRODUCTION

The conduction of a comprehensive set of road surveys such as Location Reference Points (LRPs), Roughness (IRI- International Roughness Index), and Global Positioning Systems (GPS) surveys is vital for well organized road asset management. Numerous data types need to be collected to successfully apply a Road Asset Management System (RAMS). These include inventory and condition data among others. Various technologies are available to provide information to asset managers, policy makers and funding agencies concerning their road network (Fawcett et al., 2002). This information is intended to foster informed decision making. Besides knowledge of the mere network, i.e. inventory data, information relating but not restricted to, the spatial location of the roads, their condition, pavement type, traffic and features that are located along the road including bridges, sign posts and culverts are also quite relevant to the asset management departments.

Often, data collection attempts for road maintenance requirements are spearhead in a big way. A team of road engineers is sent out to collect Information Quality Level 1 (IQL-1)[1] data on a whole road network of say 500km. In reality however, only sections of this network covering for example < 30% of the road is usually in need of immediate attention. The low cost GIT based technology discussed in this paper is intended to introduce the concept of preliminary data collection of road condition on the whole length of the targeted road from which detailed data collection can proceed along the identified critical sections. The data levels recognized by the World Bank Paterson and Scullion (1990) were taken into account while collecting data with this technology. The data collected was only appropriate for the planned use, which as earlier mentioned was to preliminarily highlight maintenance required sections for further analysis. The technology collected data at IQL-3, which data could then be used in preliminary screening studies for further road maintenance decision making. It is intended that in this screening study, sections that warrant more detailed investigation can be identified and analyzed more technically and at depth. This is basically to avoid detailed data collection on the entire length of road, especially in financial stringent situations, which data ends up not being considered for priority maintenance actions.

This technology is composed of a vehicle, two digital video cameras, 2 GPS receivers and a notebook computer. It involved video logging the road and storing GPS coordinates of the video-log. Video-log data collection technologies are quite popular of recent. This is partly because, the time spent in acquiring the video-logs and GPS signals in the field is very short. The unprocessed video is quite informative at onset as compared to cumbersome manual data collection techniques that obviously require processing before they can make sense to the decision maker. Even though augmenting the video captured is time consuming, this process happens in the office/ laboratory far from the uncertain field conditions (Silva et al., 2003). In Silva et al. (2003), a list of platforms for a couple of navigation and mapping sensors has been discussed. Vans and trucks are majorly used, but also, cars, trains and aircrafts, to develop the vast types of equipment for this navigation and mapping. Digital compasses, GPS, gyros, and odometers were used for navigation while, a number of CCD digital cameras, analogue cameras and digital camcorders were used for mapping. These mobile mapping systems have various names as decided upon by the various developers. Details can be obtained from Silva et al. (2003).

1 High resolution and precision data is referred to as High Information Quality level) data. These information quality levels range from IQL-1 to IQL-5 in the order of reducing resolution and precision. This is often agreed upon by relating the hierarchy of needs as well as the analysis methods. IQL is a very fundamental consideration to avoid collection of data in much more detail than is actually required by the analysis.

The two main objectives of defining the technology are, 1. To recommend the use of low cost GIT concepts to obtain an inventory of road condition data for preliminary road maintenance decision support, and 2. To provide a road condition inventory base map of the road network This development is part of an ongoing research targeting the accentuation of GIT use in the road infrastructure maintenance division of Kampala, Uganda.

2 THE ROMDAS TECHNOLOGY

The most common video surveying technology in use to date is the well-known ROad Measurement and Data Acquisition System (ROMDAS). The ROMDAS was developed as a generic system for collecting data on road condition and travel time (Rashid and Tsunokawa, 2006). With ROMDAS, it is possible to conduct roughness surveys, travel time and congestion surveys, condition ratting surveys, inventory surveys, moving traffic surveys, transverse profile/rutting surveys, video logging surveys, collecting Global Positioning Systems (GPS) data, recording the location of digital photographs, and creating voice records which are associated with road attributes (Sodikov et al., 2005, Hunter and Porter, 2005, Fawcett et al., 2002). ROMDAS is one of the few data collection systems that has been specifically designed for developing countries to be used by local road controlling agencies (Fawcett et al., 2002). In Uganda, the Project Management and Engineering Consultancy (PROME) is using ROMDAS to collect data to populate the national road databank and later design an asset management system. This data is to be used as a decision-making support tool for preparing annual and multi-annual maintenance and investment work plans and reporting in general. The system consists of a video camera and several measuring devices including a gyroscope, GPS receivers, odometer, etc, mounted on a vehicle, together with software that processes the measurements. As the vehicle moves, the visual road condition is recorded by the video camera. Meanwhile, the ROMDAS maintains synchronization between the video data and the discrete data acquired by the several measuring devices mentioned (Dragan Ivetic et al., 2010). It is a flexible well documented system that involves 3 modules (survey, record, and play back) and is easy to transport. Fawcett et al. (2002) provide an elaborate architecture of the ROMDAS

Regardless of its obvious advantages, the ROMDAS collects so much data that in many situations remains useless besides creating storage and analysis problems for the road management departments. The Low cost GIT based technology that is proposed in this paper suggests preliminary data collection for the targeted road sections. The results of this preliminary survey then lead to more detailed data collection with in depth analysis, probably with the aid of the ROMDAS. The proceeding data collection and analysis phases should then be aimed at higher IQL data from this low cost recommended technology.

3 LOW COST GIT DATA COLLECTION TECHNOLOGY

This low cost GIT data collection methodology is similar to the ROMDAS technology. The technology has been prototyped for selected roads in Jinja district of Uganda in East Africa. The main objective of this ROMDAS likened technology is, to develop a low cost GIT based data capture methodology for the road condition, which technology that can be used by road managers in decision making positions by highlighting maintenance required sections for further analysis. It is composed of a vehicle (guarded with rails at the front), two digital camcorders (a Canon HF 11 and a Sony HDR CX 520 VE), 2 GPS receivers (DG-100 GPS Data logger + receiver and BT-359S Bluetooth GPS receiver), and a notebook computer (Panasonic Toughbook CF-U1 running windows XP). The Sony camera was modified to record IR and the Canon was maintained with real color. The reason for the use of these 2 cameras was for comparison of real and infrared imagery of the captured road sections. This comparison is briefly discussed under the discussion section. The digital camcorders are mounted at the front of the vehicle on the guard rails, see Figure 3-3. The GPS receivers are placed at the dash board of the vehicle. The notebook computer and GPS receivers are configured to record the position of the vehicle, its time, speed and altitude. The visual road condition is recorded by the camcorder as the vehicle traverses the road. Meanwhile, the GPS loggers are synchronized with the GIS on the notebook computer to allow for tracking of the video path and making of annotations at LRPs and important features-road architecture along the road section.

This technology is a position towards Intelligent Transportation Systems (ITS). ITS intend to use existing Information Communications Technologies (ICT) capacity more effectively by collecting detailed spatial and temporal data about the transportation network and using this information in transportation system management. The accomplishment made with this technology is initially an awareness of the potential of GITs in the road infrastructure management sector.

Figure 3-3: Cameras clamped on the vehicle guard rail

It is also pointer to the road maintenance organisations that preliminary data collection is a requirement before higher IQL data can be collected. Besides the expense of data collection, these high IQL data require technically involving analysis techniques that should not be unnecessarily performed on the whole length of a road.

3.1 Methodology

The network was prior divided into manageable sections that began and ended at known LRPs. The following hardware components were used; A vehicle pickup cabin with front guard rails, 2 GPS receivers (the 2nd handset was for backup purposes), two digital video cameras (Sony HDR CX 520 VE and Canon HF 11) and a note book computer. The two cameras were mounted onto the guard rail of the vehicle. The Canon HF 11 used visible light films that were recorded in full HD 1080p[2] (1920 * 1080). The Sony HDR CX 520 VE recorded in 1080i and was modified to Near Infrared (NIR). For purposes of calibration, initially, two (2) B+W 093 filters were placed in front of the lens of the Sony, to filter out the visible light (VIS). This was because light was so intense at the time of the survey and the automatic exposure measuring in the camera is only calibrated to VIS. An equivalent of a strong grey filter was placed outside the lens as light continued to be intense, see Figure 3-3. Fully charged cameras and GPS receivers were maintained with ready memory space.

At the start of the survey for a particular road section, link nodes were predetermined for location referencing. Actual location referencing was performed during the course of the survey. The components qualifying linear referencing methods were professionally dealt with in the following manner;

1. Identification of a known point. These points comprised of KM posts, bridges and junctions and at such points, digital photos were taken. They were also annotated in the map document as GPS logging was taking place.
2. Direction. The researcher narrated in the film the current location of the survey vehicle and the direction that the vehicle was heading to. Sketches of this information were also made to the map document.
3. Distance measurement. The vehicle odometer was used to make distance measurements.

No field signage was installed for this survey exercise. Instead the network was broken down into links and sections. Data capture began from junction to junction and displacements were measured from 0 metres at the first node in the increasing direction of the moving vehicle. Sections then began and ended at more clearly fixed benchmarks.

The GPS receivers were placed at the dash board of the vehicle. The Panasonic Toughbook CF-U1 running with windows XP and ArcGIS 9.3 has an inbuilt GPS. It was also configured and synchronized together with the DG-100 GPS Data logger + re-

2 The p stands for progressive, meaning that every row of every frame is recorded in contrast to the 1080i, i standing for interlaced, where lines 1, 3, 5... of the first frame are recorded, and 2, 4, 6... of the second frame, and 1, 3, 5... of the third frame and so on.

ceiver and BT-359S Bluetooth GPS receiver to record the position of the vehicle as it moved. On the notebook computer, the researcher maintained an annotated shape file of the path taken by the vehicle with a Landsat ETM+ image at the background. At LRPs, the researcher made remarks in form of drawings and descriptions as annotations to the shape file see Figure 3-4. Features relating to roundabout locations, taxi parks, water falls (Bujagali falls to be precise), railway crossings, airfields and the golf course location were demarcated on the shape file. Note that these are referred to as events when modeling transportation data in GIS and as such, are vital data requirements.

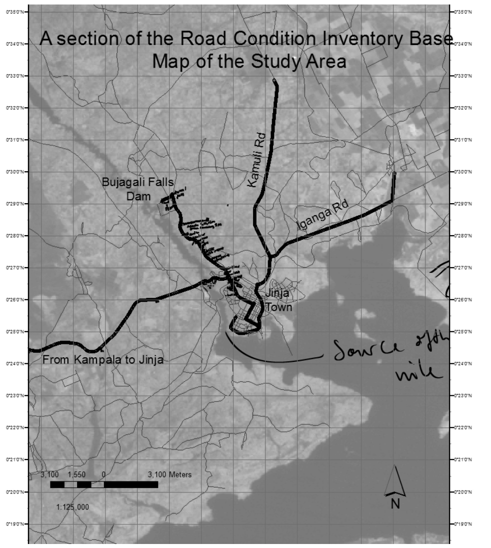
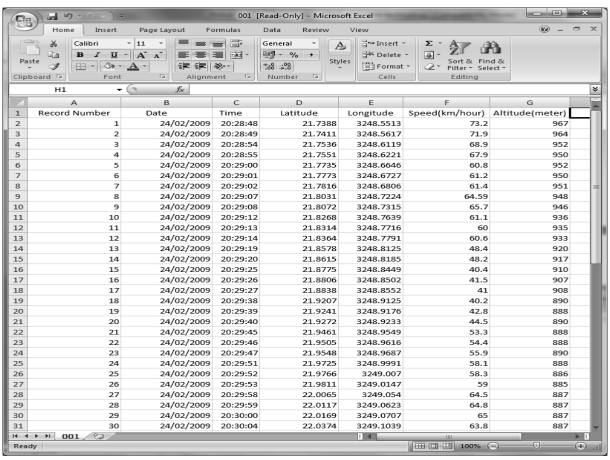


Figure 3-4: Field Base Map Document



Record Number	Date	Time	Latitude	Longitude	Speed(km/hour)	Altitude(meter)
1	24/02/2009	20:28:48	21.7388	3248.5513	73.2	967
2	24/02/2009	20:28:49	21.7411	3248.5617	71.9	964
3	24/02/2009	20:28:54	21.7536	3248.6119	68.9	952
4	24/02/2009	20:28:55	21.7551	3248.6221	67.9	950
5	24/02/2009	20:29:00	21.7735	3248.6646	60.8	952
6	24/02/2009	20:29:01	21.7773	3248.6727	61.2	950
7	24/02/2009	20:29:02	21.7816	3248.6806	61.4	951
8	24/02/2009	20:29:07	21.8031	3248.7224	64.59	948
9	24/02/2009	20:29:08	21.8072	3248.7315	65.7	946
10	24/02/2009	20:29:12	21.8268	3248.7639	61.1	936
11	24/02/2009	20:29:13	21.8314	3248.7716	60	935
12	24/02/2009	20:29:14	21.8364	3248.7791	60.6	933
13	24/02/2009	20:29:19	21.8578	3248.8125	48.4	920
14	24/02/2009	20:29:20	21.8615	3248.8185	48.2	917
15	24/02/2009	20:29:25	21.8775	3248.8449	40.4	910
16	24/02/2009	20:29:26	21.8806	3248.8502	41.5	907
17	24/02/2009	20:29:27	21.8838	3248.8552	41	908
18	24/02/2009	20:29:38	21.9207	3248.9125	40.2	890
19	24/02/2009	20:29:39	21.9241	3248.9176	42.8	888
20	24/02/2009	20:29:40	21.9272	3248.9233	44.5	890
21	24/02/2009	20:29:45	21.9461	3248.9549	53.3	888
22	24/02/2009	20:29:46	21.9505	3248.9616	54.4	888
23	24/02/2009	20:29:47	21.9548	3248.9687	55.9	890
24	24/02/2009	20:29:51	21.9725	3248.9991	58.1	888
25	24/02/2009	20:29:52	21.9766	3249.007	58.3	886
26	24/02/2009	20:29:53	21.9811	3249.0147	59	885
27	24/02/2009	20:29:58	22.0065	3249.054	64.5	887
28	24/02/2009	20:29:59	22.0117	3249.0623	64.8	887
29	24/02/2009	20:30:00	22.0169	3249.0707	65	887
30	24/02/2009	20:30:04	22.0374	3249.1039	63.8	887

Figure 3-5: GPS data as an excel sheet

3.2 Discussion

There are numerous providers of the state of the art data capture equipment for road network surveys (Fawcett et al., 2002). This particular low cost GIT based technology collects 2 basic categories of information; spatial coordinates using GPS and video logging for inventory and condition records. The software coming with Global sat GPS allows saving the GPS locations in different file formats. Figure 3-5 shows a snap shot of the GPS data in an excel sheet. The attributes to the captured records are Date, Time, Latitude, Longitude, Speed (Km/Hr) and Altitude in Meters. Figure 3-6 shows a snap shot of the Google Earth coverage from the KML file. The pegs along the road indicate the vehicle positions during the survey.

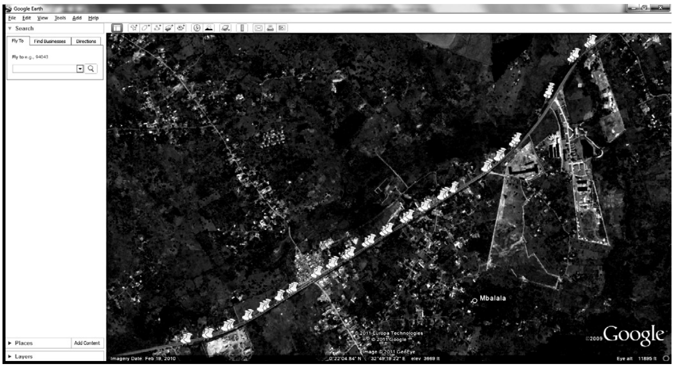


Figure 3-6: KML plot of the GPS log

Two cameras were used and logging was done along both the from and to directions. An event point or detail on the road can therefore be seen from several positions of the video-log. If analysis in one position was not effective, then successive positions would be used for more informative analysis. Figure 3-7 shows a snap shot of the video-log of the same position captured by the two different cameras at the same time instance.

a. Canon (real color) camera *b. Sony (Infrared) camera*

Figure 3-7a&b: Sections of Bujagali road captured at 10am

It is imperative to highlight the differences in the video-logs from the two different cameras and their causes. The cameras were mounted at the same side of the vehicle. In the forward direction of the vehicle, the canon was clamped on the left and the Sony on the right (further outward). This explains the difference in the portion of the road that is visible from each camera at the same time instance.

When recording from inbuilt Bluetooth GPS, the user presets the rate at which recording should be made. This would naturally be inclined on the availability of satellites and the strength of the signals. Initially, the GPS locations were captured every second. This created a lag in the base map being annotated. This was then reset to 5 seconds which proved exact in tracing the vehicle according to its speed. As compared to the ROMDAS recommended speed, the average speed of the vehicle for the sample dataset is 56.535km/hr. This clearly shows that the technology advocated is still within the guidelines of the well documented and recognized ROMDAS technology. A comparison of the ROMDAS and this low cost GIT technology is summarized in Table 3-2.

3.2.1 Challenges and their effects

This low cost GIT technology is not without challenges. It is affected mainly by three issues; Rainfall -since the cameras are clamped outside the vehicle, no survey can be done during the rain, -extreme sunshine especially with the Sony modified camera. This was irrespective of the filters used. Moderation of speed was also of concern considering the fact that it is majorly done by the driver of the vehicle.

Table 3-2: Comparison between the Traditional ROMDAS and the GIT Based Technology

Comparison parameter	ROMDAS	Augmented technology
Calibration	• Odometer, Bump integrator and video camera (tweaks and adjustments for frames per sec, autofocus disabled.) are prior calibrated	• See filter placement under methodology, • Fully charged battery, • Readily available memory space
Location Referencing	• Mainly performed as an independent activity. • LRPs defined and documented prior to the survey	• Sections links and nodes decided upon prior to the survey, • LR performed during the survey, Pictures of reference points taken together with narration at start and end of video-log, • LRP annotations made on the map
Speed	• Maintained at <= 60km	• Managed by the driver depending on firmness of the digital cameras. • Average for these particular surveys was 56.535 Km/hr

Collected data	Speed, IRI, GPS locations, video-log, etc.	• GPS locations, speed • Video-log, i.e. Visual surface condition of cracking and potholing • Transverse profile • Traffic density- can be observed from the video-log

The snap shot in figure 3-8 is of the same location as that of figure 3-7. The log of figure 3-7 was captured in the morning with a clear day's sky. That of figure 3-8 was captured on the same day but after some rain in the afternoon. Notice that videos from both cameras register better imagery with a clear sky. The real color image however shows limited contrast. For the IR image, the log captured shortly after the rain is remarkably of better clarity than the one captured during high rise sunshine. This justifies the need for the extra grey filter especially at maximum sunshine. The spectral nature of light is known to influence imaging and image properties. It is therefore recommended that for the best video-log, the sun should not be high above the horizon, for when in that position, the sun lights directly into the potholes limiting contrasts in the captured video. Although the differences are sometimes negligible, better images are produced in the early mornings or later in the evenings. Even if traffic counts are recommendable with this technology, it is advisable to survey at low traffic times to allow for more visibility of the road condition.

a) Real color image *b) IR image*

Figure 3-8a&b: The same section of Bujagali road as in figure 3-7, captured after rainfall

3.2.2 Sony HDR CX 520 VE and Canon HF 11 cameras compared

The major difference between the two camera products was as a result of the image stabilizing system. The Sony has a far better optical image stabilizing system. Both were mounted at the same holder, the Sony even further out, which would mean more movement in bumps. However, the vehicle bumping affected the canon camera much more than the Sony camera. Additionally, the Sony has an advantage of the inbuilt GPS showing the coordinates when played from the camera. Despite its poor image stability, the canon HF 11 has the best image quality available. In this case, the sensitivity of a camera is inversely proportional to its image stability. It records on internal RAM 32 GigaByte, alternatively on a SD card which gives more hours of filming and quite long battery time. A recommendation for the image stability would be, to mount the cameras 1. at the rear of the vehicle or 2. at the wind shield, as much as possible towards the rotational centre of the vehicle to minimize the engine's bumping effect.

In November 2010, Microsoft released the Kinect Xbox 360 video game console. Numerous developers are researching possible applications of Kinect that go beyond the system's intended purpose of playing games. The Kinect has 2 video recording devices, the RGB camera and 3D video sensors which is basically scanning the vicinity and producing depth models. The authors are currently investigating working with the kinect to capture visual road condition. With the kinect's depth measurement possibility, the size and extent of potholes can be calculated for purposes of estimating material required for pothole fixing. The suggestion is to mount it downward on the back of a car to register surface roughness of the road. This could even produce better results during the night as the irritating solar radiation together with the traffic is obviously eliminated.

4 CONCLUSION

The technology provides both a practical and flexible solution for keeping up to date with road inventory and condition parameters. The captured video-log and GPS data prove that this low cost GIT based technology is an effective approach to inspecting road pavement condition and to mapping road street furniture and other important features along the roads. It provides for full visual and spatial referenced road condition. These details are quite important for decision making in the planning of road maintenance works. The main quality of the GIT methodology is the completeness, accuracy and effectiveness of acquiring the field data in a short time. Its major contribution is the ability to immediately provide an mxd document of the survey path with annotations explaining the road parameters as observed during the survey. At the proceeding surveys from this preliminary finding, increment in the information quality level (IQL) of the data captured is recommended. This is because for further analysis on the recommended sections for priority maintenance, more technical and in-depth data analysis is required. This research proposes data mining of spatial video databases to facilitate routine and periodic maintenance decisions. Additionally, there are advancements in camera models on the market which can be modified and adopted for scientific studies. A modification of the varieties, beyond their intended purpose, should be considered for scientific research of this nature.

Even though data collection is considered expensive and time consuming in several road management studies, this video logging technology like all others is effective in managing this challenge. Since the platform (a vehicle in this case) carries all the hardware and software in just one route, then, in compliance with the appropriate sampling interval, and the IQL standards, all possible data that can be collected should be collected for each route. Whether to use the data will eventually depend on management requirements at that time. This is however in contrast with Bennett et al. (2007)'s advocate for collection of only the data that is needed for the present purpose.

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Part 4 - CONCLUSION

4.1 Summary and Discussion of the Papers

4.1.1 Paper I

Despite the digital divide in the road maintenance sector, stake holder organisations like the national road authority, the ministry and project supported consultancies can already benefit from the available freeware and Open Source software. These organisations are equipped with basic staff qualifications to manipulate captured spatial video and photographs to best visualize road condition which is a requirement for maintenance decision making. For software developers, some of these freeware allow for plug-ins whenever there is need to customize their applications. And besides, the use of Open Source software is often a gateway to more advanced operations with enhanced software capabilities.

4.1.2 Paper II

The gaps in GIT use in the RIM sector have been found to be majorly social but also technical in nature. Socially, these gaps include;, the inadequate institutional arrangement that should allow for lasting partnerships and the absence of data sharing and collaboration. Technically, GITs are not integrated in the working procedures of the organizations, there are no standards for the geographical data and in effect this cannot lead to a coordinated GIS infrastructure. There is also lack of a data foundation at national and local levels. The limitations to accessing of these GITs in RIM include; the absence of a policy on the standard use of GITs, budget constraints, inadequate geospatial capacity at all levels and the digital divide between the involved organizations. Other than the principle that organizational stand alone GIT usage is costly and time wasting, the approach to assessing gaps and limitations was based on the principle of causality. This is the principle that everything should have a cause and that the cause must precede its effect. The limitations and gaps relationship is therefore a causality relationship where the limitations are the cause and the gaps are the effect.

As the backbone to the gaps and limitations facing the usage of GITs in the road maintenance sector is the absence of a policy governing custody and use of spatial data. This absence of a policy does not only affect GIT usage in RIM but also several other departments that rely on the use of spatial data throughout the country. The Uganda national ICT policy framework of May 2002 recognises that ICT plays a big role in the stimulation of national development and globalization of the economy. However, this ICT policy does not yet recognise the role of geo-information. It is envisaged that if the right policies are in place, then the issues like budget and GIT inclusion in the working procedures of departments will be well catered for. Otherwise for now, the use of GIS in Uganda can be characterised as user- or project-driven, and not due to any specific government policy implementation. There is no central body charged with implementation or mandate to co-ordinate GIS or SDI activities. Uganda has a lot to learn from the experiences of some African countries like Ethiopia, Sierra Leone, and South Africa, among others, which have enacted acts for spatial data infrastructure development. These countries have gone steps ahead in developing policies for the management and utilization of geographic data. Other countries with relevant SDI experiences which could provide best example for Uganda include; New Zealand, Canada, Croatia, EU INSPIRE, Netherlands, Sweden and United States of America. These countries have established a wide range of policies, agreements, geodata, institutional frameworks, human resource development strategies, financial arrangements and monitoring activities from which Uganda can draw examples to develop its NSDI, an infrastructure that will eventually boost the development of GIT usage in all relevant sectors in the country. Presently, the ongoing NSDI initiative has made a recommendation to the Uganda Bureau of Standards (UBOS) together with the National Planning Authority (NPA) / the National Interagency Spatial Data Infrastructure Committee (NISDIC) to adopt open standards for the SDI. The existence of common standards enables efficient data integration and exchange of data among stakeholders. Such that as the NSDI is yet to be achieved, these standards can still be used by the stand alone GIT users to further their knowledge based decision making using GI. However, there are still unresolved issues on the NSDI funding, leadership, legal framework, technology, and policy coordination.

4.1.3 Paper III

The documented algorithm is nondeterministic, meaning that it is not sequential but iterative in nature. This is because the devised strategies are dependent on and supportive of each other. The greatest advocate is the need for a policy to back the use of GIT since it is identified as the backbone to all the gaps and limitations that were found dominant in the sector. It is also noted that in the long run, GITs would in self be used in routine support of policy making as pragmatic from their advantages of facilitating informed decision making. Embarking on the diffusion of GITs to the contractor category of the stakeholders is similarly quite fundamental in this process of enhancing usability of GITs in the sector.

The standard requirements which comprise a successful institutional GIT model are found to include; drafted and passed policies allowing for long term upper management commitment to the GIT undertaking, sufficient allocation of resources, adequate staffing in terms of numbers and skills/ competencies, timely and sufficient training and organizational communication to smoothen the transition to full utilization. Data sharing and collaboration through partnerships and research networks between; government agencies, research and training institutions, the private sector and the non government sector are also known to boost institutionalization of technology advancements. This then evolves into the triple helix concept of problem solving. This concept involves harnessing and leveraging the complementary expertise of academia, industry and government to facilitate innovation and novel collaborative processes for creative development. In his way forward communication of the NDP 2010/11-2014/15, the president of Uganda urged the private sector, the civil society and academia to work together with the government in order to realize the objectives set in the plan. Due to the cost of maintaining stand alone GIT initiatives, the institutionalization of GITs in the sector, a concept that requires prior diffusion mechanisms for purposes of bridging the present digital divide, is an approach that should be adopted. International collaboration and cooperation between developed and undeveloped countries also come by with a bit to learn from. On adoption of the devised strategies to enhance GIT use in RIM, there will be need to develop effective frameworks for evaluating the utilization of GITs. These frameworks have been found critical to the long-term efficiency of GITs.

4.1.4 Paper IV

Despite the fact that road infrastructures are constantly changing due to various factors, there are hardly any strategies for the continuous updates of the road inventory and condition data. This is attributed to the costly ventures concerning the data collection phase of the road maintenance aspect. Paper IV is introducing a low cost GIT based methodology for road condition data collection that can be used for preliminary decision making. With this methodology, the idea is to identify the road sections that need urgent attention for maintenance and it's only along these sections that in depth data collection and analysis is made to plan for road maintenance implementation. In addition, the furniture and architecture of the road in survey can be updated and availed both as GPS coordinates and in form of a map document.

The main character of this proposed low cost GIT methodology is the accuracy, completeness, and effectiveness with which field data is collected. The ability to provide a map document, already at the end of the survey, showing the sections of the target road in need of urgent maintenance is a major contribution of the technology.

It is suggested that in addition to the ordinary ROMDAS hardware and software applications, excerpts of this methodology be included to guide further analysis of the collected data. There is however a contrast with Bennet et al. (2007)'s guidelines on data collection. Bennet et al. (2007) urge that because of the cost and efforts required to collect road management data, only data required for the purpose at hand should be collected. However, this technology like other mobile video logging survey equipment can do otherwise. Depending on the number and size of equipment that the survey platform can hold, it is possible to collect as much data as possible. The storage and analysis of this data would then be the concern. The methodology is effective in conducting periodic and routine visual road inspection and presenting it to administrators who usually perceive more by seeing than reading. In the conception of this technology, it is discovered that there are a variety of "good" consumer cameras on the market many of which could possibly be modified for research purposes as witnessed with the Sony HDR CX 520 VE and Kinect xbox 360 that will be used in extending this technology.

4.2 Research Contribution

Sustainable development in Uganda is guided by adherence to the MDGs and the National Development Plan (NDP) 2010/11 – 2014/15 of Uganda. This research is aligned with goal 8 of the MDGs which strives to make available the benefits of new technologies, especially information and communications technologies in developing a global partnership to development. Unless initiated at a local level achieving global development is rather difficult. Enhancing GIT use in the transport sector is a bottom up approach towards availing accessibility to ICT for sustainable development. Objective 5 of the NDP of Uganda is to promote science, technology, innovation and ICT to enhance competitiveness. This research is addressing the low application of science and technology key binding constraint of the NDP.

Apparently, research in the road maintenance sector is yet to tackle various ways in which GITs can be used to further their performance as decision support tools. Through this research however, it has been brought to book the gaps and limitations that are challenging the institutionalization of GIT in the road infrastructure maintenance division. It has created an awareness of the potential of GITs in the RIM through interaction with stakeholders in the sector and presentation of research findings and progress at a couple of conferences.

A nondeterministic algorithmic framework for the accentuation of GIT usage in road infrastructure maintenance in Uganda has been recommended. In this model, strategies are given for which the RIM sector can pursue in order to adopt institutionalization of GIT.

It is obvious that enormous amount of money is required to maintain up to date data inventory of the condition of roads so as to keep abreast with the right maintenance required decisions. This research proposed a low cost GIT based methodology for preliminary RIM decision support. Instead of under taking the routine road condition data collection for every 2-3 or even 5 years depending on the class of road, this technology serves to indicate which sections of roads require urgent maintenance attention. It is then for these sections, that in depth data collection and analysis should proceed.

4.3 Way Forward

Even though a couple of papers have been published about the ongoing research, there are analyses that are accomplished during the forthcoming stages of the remaining PhD. studies.

1. The GIS analyses on the independent mapping of the roads visa vie what is being used for road maintenance is still on-going. In depth analysis of these independently collected data is still required
2. The dynamic segmentation data model has been recommended for road maintenance data of the RIM division. A prototype model is to be developed and tested with the division's data in Uganda.
3. A workshop is planned (see section1.5.5) where a presentation to the participants shall be made of the framework developments to-date. The intention is to have a fully participatory approach to the framework development by having a more stakeholder involvement in the research. The developed framework has evolved with consultation with just a representative fraction (a third (1/3) of the stakeholders in the RIM sector. For this nature of development however, input from a generously proportioned stakeholder community is highly recommended.
4. Manuscripts dealing with the following subjects are presently under preparation;
    i. The nature and requirements for road maintenance data,
    ii. The dynamic segmentation prototype data model,
    ii. Detailed guidelines to implement the developed framework

4.4 Final Remarks

Basing on the objectives and research questions that were set for the PhD research, the research has so far managed to, establish the gaps and limitations in the GIT usage for RIM, recognise the superiority of the GIS-T dynamic segmentation data model for road maintenance data and develop the algorithmic framework for accentuation of GIT in RIM. Additionally but not directly in line with the research objectives, a low cost GIS-T data collection methodology for preliminary road maintenance decision support has been commended. This technology is to be extended using the Microsoft's Kinect Xbox 360 video game console to go beyond the kinect's intended purpose of playing games. Similarly, there is need to develop a prototype dynamic segmentation data model for road maintenance data in the country. It is also a requirement to further harmonise the developed framework with a more representative fraction of stakeholders and other researchers in the sector through a workshop to be scheduled in due course. In addition, an expansion on the guidelines for the RIM organisations to adapt this algorithmic framework is pending.

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