Geographical Information Technologies – Decision Support for Road Maintenanace in Uganda

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ABSTRACT

This study set out to develop a framework within which the use of Geographical Information Technologies (GITs) can be enhanced in Road Infrastructure Maintenance (RIM) in Uganda. Specifically it was guided by 3 objectives; 1. To assess the gaps in the use of GITs for RIM in Uganda and the limitations to accessing these technologies, 2. To develop a methodological framework to enhance the use of GITs in RIM and 3. To develop a Geographical Information Systems for Transportation (GIS-T) data model based on the road maintenance data requirements. A participatory approach through a series of interviews, focus group discussions, workshop & conferences, document reviews, field observations & measurements and GIS analysis were employed.

Based on the Spatial Data Infrastructure (SDI) concept and the principle of Causality, the gaps and limitations were established to mainly be concerned with data and organisational constraints as opposed to technical issues. They were classified to include; inadequate involvement of GITs in organisational activities, inappropriate institutional arrangements, absence of data sharing frameworks, budget constraints, insufficient geospatial capacity, digital divide in the perception, adoption & affordability of GITs among the stakeholders and the absence of a road maintenance Spatial Data Infrastructure (SDI).

A methodological framework, comprising of 6 strategic components was developed to enhance the use of GITs in RIM. This included enactment of relevant policy components to guide GIT use, continuous capacity building, establishment of a road maintenance SDI, fostering collaboration and spatial data sharing frameworks, budgetary allocation based on defined activities inclusive of GIT initiatives, and adoption of a dynamic segmentation data model.

Conceptual and logical data models were developed and proposed for the Sector. The conceptual model, presented using an entity relationship diagram, relates the road network to the point and line events occurring on it. The logical object relational model developed using the ESRI provided template represents the road and the point and line events in a total of 19 object classes.

The Study concludes that in order to ground GIT benefits in the sector; technical, data and organisational concerns involved in GIT undertakings should be accorded equal emphasis. Institutionalisation and diffusion of GITs as aspects of the component strategies are regarded capacity building mechanisms earmarked to boost success in GIT initiatives. Further research on diffusion and funding models for GIT initiatives is recommended. It is suggested that aspects of the proposed model be considered when establishing GIT standards for the sector. The RIM sector is encouraged to embrace Science and Technology and to participate in Research and Development and particularly to adopt the culture of innovation considering the ready availability of off the shelf equipment, freeware and open source software that can foster informed decision making.

Key Words: Data Model, Dynamic Segmentation, Geographical Information Technologies (GITs), Geographical Information Systems for Transportation (GIS-T), Linear referencing, Methodological Framework, Research and Development, Road maintenance, Road Infrastructure Maintenance (RIM), Science Technology and Innovation, Spatial Data Infrastructure, Uganda.

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And to all whose names I have not mentioned, my family, in-laws, friends and workmates who have thought, prayed and stood by me in various ways, May God richly bless you.

Lydia Mazzi Kayondo - Ndandiko
September 2012

In memory of my late father George William Kayondo
You always shared with me of your hard study and urged me to follow suit
That has always kept on my heart,
and now it bears fruit, 20 years after your departure!
RIP Daddy

To my dear Mother and friend, Mrs Ruth Kayondo
Thank you for all life's encouragement

To my Children, Brianna, Bridgette and Bruno
I urge you to follow your dreams passionately

To my husband Charles
Thanks for all the support

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LIST OF ACRONYMS[1]

DSS	Decision Support Systems
Dynseg	Dynamic Segmentation
FGD	Focus Group Discussions
GI	Geographical Information
GIS	Geographical Information Systems
GIS-T	Geographical Information Systems for Transportation
GPS	Global positioning Systems
GITs	Geographical Information Technologies
ICT	Information Communication Technology
IQL	Information Quality Level
IRI	International Roughness Index
KCCA	Kampala Capital City Authority
LRM	Location Referencing Method
LRP	Location Referencing Point
LRS	Location Referencing System
MDGs	Millennium Development Goals
MIS	Management Information System
MoLG	Ministry of Local Government
MoWT	Ministry of Works and Transport
NDP	National Development Plan
NSDI	National Spatial Data Infrastructure
NMO	National Mapping Organisation
OPRC	Output and Performance Based Road Contracts
OSM	OpenStreetMap
PCI	Pavement Condition Index
PROME	Project Management Engineering
RAMPS	Road Analysis Management and Planning Software
RIM	Road Infrastructure Maintenance
ROMDAS	Road Measurement and Data Acquisition System
RS	Remote Sensing
SDI	Spatial Data Infrastructure
SDSS	Spatial Decision Support Systems
STI	Science, Technology and Innovation
TIS	Transport Information System
TRB	Transportation Research Board
TSDMS	Transport Sector Data Management System
TTCA	Transit Transport Coordination Authority
UBOS	Uganda Bureau of Statistics
UML	Unified Modelling Language
UNRA	Uganda National Roads Authority
URF	Uganda Road Fund

1 Throughout the Thesis, acronyms are bolded on first mention. Only key acronyms and those that are used more than 5 times in the Thesis have been included in the list.

CHAPTER ONE
GENERAL INTRODUCTION

1.1 Background

Maintenance of the road transport network of a country is pivotal to the overall infrastructural development. Most development projects depend on good road transport network infrastructure for delivery of goods and services (Babu, 2006). For sustainable development of a country, a well maintained road transport network infrastructure is fundamental in the promotion of socio-economic and industrial developments. Economically, road transport infrastructure has been found not only to boost the livelihood of cities, which are the major sources of national economic activities and growth (Gwilliam, 2002) but also the agricultural sector in the country side. With the economic health of a country directly linked to mobility, transport inevitably accounts for a substantial proportion of a country's Gross Domestic Product (GDP) and therefore is central to its development (ibid).

The road transport sector in Africa also contributes significantly to the economic growth and poverty eradication in the continent through various ways, especially, through trade and tourism. However majority of the roads are unpaved and the burden of maintaining them is quite high. In effect, many of the roads are rough and impassable. The rural residents in particular suffer from poor access to markets, health units, schools and high transport costs. The inadequate road infrastructure is also increasingly limiting farmers in applying pesticides and fertilisers and transporting their produce on harvest. In an effort to facilitate import and export activities, the East African Community (EAC) identified five major transport corridors in the East African region[2].

[2] http://www.eac.int/infrastructure/index.php?option=com_content&view=article&id=109&Itemid=129

In Uganda's case where road transport is the predominate mode, road maintenance is an important strategy in the Country's development. The Uganda national budget identifies roads as one of the 6 key service delivery centers in the country including agriculture, energy, health, education and water (Kiwanuka, 2012). In this light, roads have always been one of the priority areas for budget allocation in the country (Bbumba 2010, Kiwanuka, 2011 and Kiwanuka, 2012). In addition to having one of the largest shares, the recent budget (Kiwanuka 2012) proposed 78% increase in allocation to the works and transport sector for construction, rehabilitation and maintenance of roads in the country. The absence of a fully functional railroad to handle both freight and long distance routes has created strain on the road infrastructure and stimulated the need for effective road maintenance. The over reliance on road transport as opposed to other modes (rail, marine, and air transport) has also been identified in the Uganda **National Development Plan (NDP)** as a constraint to the performance of the transport sector (NDP, 2010). This matter of reliance on the road transport network calls for the formulation and adoption of an effective road maintenance plan that will ensure that the roads are in a functional state to spearhead the country's businesses.

Instances of poor transport services in Uganda have been documented by Ken et al. (2008), Grimaud et al. (2007), Transit Transport Coordination Authority (TTCA), TTCA (2004) and Mukwaya (2001). In particular, Mukwaya,(2001) has noted that the road infrastructure was developed in a chaotic manner, with no plan for a coordinated and rationalized use of modes and routes. As a result, roads have suffered from negligence leading to road infrastructure failure. Attempts to maintain roads have frustrated users as the roads almost immediately develop potholes after repair. Worse still, road maintenance has been undertaken in an ad hoc manner, culminating into an unsatisfactory state.

Dimitriou and Banjo (1990) have discussed transport problems of third world cities which include traffic congestion, impacts to the environment, and high road accidents. For Uganda, problems relating to traffic congestion, high road accidents, weak institutional support leading to poor definition of the problems at hand, and differing technology transfer priorities in problem resolution still exist.

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). Preventive maintenance is a roads maintenance strategy geared at extending the life time of a road through ensuring community satisfaction. 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 development in this field of information technology requires **Geographical Information Systems (GIS)** and database management systems that are relevant to the field of transport engineering (Babu, 2006).

Authentic information relating to the condition of the transport infrastructure is a fundamental requirement for management of the road network. This information aids in the decision making process of many applications that involve transportation features. Such information should be up to date, reliable, relevant, easily accessible and affordable. The demand for new approaches in which relevant data for this resourceful transportation network can be identified, collected, stored, retrieved, managed, analysed, communicated and presented is in response to the fundamental importance of the data. Brodnig and Mayer-Schönberger (2000) assert that accurate and reliable information is a key ingredient, if not a precondition for sustainable development. They emphasize that with the growing importance of knowledge-intensive production modes, developing countries are hard pressed to jump on the bandwagon and to harness the potential of new technologies and networks.

Geospatial data, on the other hand, are a foundation for relevant and critical information for planning, engineering, asset management, and operations associated with every transportation mode, roads inclusive as per the **Transportation Research Board** (TRB) (TRB, 2004). These are data referenced to the earth surface according to a coordinate system. Because the road network is geographically located, geographical reference to it gives additional clarity. In principal, provision, operation and maintenance of the physical infrastructure of the transport sector and its related social services require a prior knowledge and manipulation of geospatial data.

The strategic plan of the National States Geographic Information Council dated January 1, 2009, highlights that 'Geospatial information is one of the nation's most important and underutilized assets in the effort to achieve greater efficiency and effectiveness of government agencies and private industries.' The use of this information is earmarked to expedite and improve government businesses, provide better citizen services, reform government management, eliminate redundancy, save money, increase agency productivity gains from technology, provide citizen-centred information and services and better coordinate the efforts of public and private-sector organisations at all levels.

Two strategic documents guiding the economic and infrastructural development of the Country are the NDP 2010/11 – 2014/15 and the **Millennium Development Goals (MDGs)**. The main purpose of maintaining a NDP is to focus the Country's efforts, particularly policies and development interventions, based on sustainable orientation of Government expenditures and implementation capacity towards removal of the most binding constraints to foster socio-economic transformation (NDP, 2010). According to the Uganda NDP (NDP, 2010), the performance of the science and technology innovation sector is constrained by inadequate focus on **Research and Development (R&D)**, and inadequate financing for:

- R&D,
- **Science, Technology and Innovation (STI)** aspects in general,
- Personnel in product innovation & services,
- Etc.

The NDP advocates for all Ugandans to embrace the principles stated therein and to apply them in the development and implementation of national programmes and projects. The respective Government sectors are urged to align their policies and strategies with the NDP. The performance of the transport sector in particular has been constrained by weak legal and regulatory framework characterised by absence of standards and codes and weak compliance resulting in shoddy work (NDP, 2010). Also earmarked in the NDP (2010) is the inappropriate institutional set up that does not separate the roles of policy formulation, planning, implementation and regulation.

The MDGs are eight international development goals that majority of the United Nations member states and a few organisations have agreed to achieve by the year 2015. Each of the goals has targets defined for its realisation. The Research is in line with target 18 of the 8th millennium goal initiative which is tasked with developing a global partnership for development by making available the benefits of new technologies especially **Information and Communications Technology (ICT)** in cooperation with the private sector.

This Research focused on exploring the potential and opportunities for enhancing the use of GITs in **Road Infrastructure Maintenance (RIM)**. GITs are broadly ICT tools for collecting, managing and analysing **Geographical Information (GI)** for decision making purposes. Emphasis was placed on addressing 2 key binding constraints as highlighted in the NDP of Uganda, inadequate physical infrastructure and low application of science and technology. The contribution of this Research is to foster science and technology in road physical infrastructure development which is directly linked to the socio economic development of the Country. The NDP foreword underscores a number of strategies chronologically devised within this Research in form of a framework intended to boost the road maintenance sector.

The following sections detail the transport services in Uganda, expound on GITs and their relevance in RIM applications and the various initiatives of their use in Uganda. The research problem is discussed, research objectives and questions are outlined, the scope is specified and the methodology is summarised. The significance of the research and structure of the Thesis summarise the chapter.

1.2 Transport Services in Uganda

The transport sector in Uganda consists of four major modes, namely, (air, road, railway and inland water transport). Road transport is by far the most dominant mode of transport within the Country, carrying over 90% of passenger and freight traffic and serving as a backbone supporting the Country's economy (Terms of Reference for **Uganda National Roads Authority, UNRA** (2007)). The Roads provide the only means of access to most of the rural communities, thus rendering their effective management crucial to the Uganda Government's strategy for economic development and poverty eradication (UNRA, 2007).

Uganda's road network comprises:

- 20,800 km of National roads under the responsibility of the **Ministry of Works and Transport (MoWT)** through the UNRA,

- 17,500 km of District roads under the responsibility of the Ministry of Local Government (MoLG),
- 4,300 km of Urban roads under the responsibility of Urban Councils,
- 30,000 km of Community access roads under the responsibility of a lower tier of Local Government (Local Council (LC) III).

Source: Road Fund (2012)

The Government is currently implementing a programme of continuous upgrading of key gravel roads to bitumen standard. These roads are characterized by bad surfaces, potholes, poor designs and inadequate furniture. The government structure of Uganda is composed of 2 tiers, namely, the Central Government and Local Government (LG). The Central Government executes its functions through ministries which receive their mandate from parliament. The 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 LG 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 Access Roads (DUCAR) 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, under (or not) the supervision of the consultant, 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. Besides the traditional data collection methodologies of land surveying, the knowledge and use of GITs is anticipated to advance the OPRC initiative.

Grimaud, et al. (2007) in their evaluation of milk quality, acknowledge that in Uganda, the road infrastructure is still inadequate. This was in spite of significant developments in the past few years, thus delaying the transportation of milk from source to user. The TTCA (2004) also indicates that the condition of the Northern corridor is poor due to inadequate maintenance. The roads are characterized by pot holes, which cause damage to cars, leading to high vehicle operating costs (VOC) (Luyimbazi, 2007). Manoeuvring through potholes with heavily damaged cars leads to high fuel consumption which is economically unsustainable.

Additionally, with a number of roads in Kampala city undergoing continuous repairs leading to traffic congestion and high accident rates, the city faces colossal dust, which, other than being an inconvenience to people, causes 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. It is common to find the same road being repaired every other half year, yet another, with worse conditions remains in the same state for several years. The decision on which roads bear priority has proved to be ad hoc and subjective. In many situations, roads are upgraded almost immediately after being repaired. Other than maintaining a continuous state of repair and upgrade that is an inconvenience in terms of dust and disease, this signifies the absence of a scheduled maintenance plan that is based on reliable information. Auditor General's report (2011) also highlights this lack of a maintenance plan as part of the challenges faced with the management of some road sections under the jurisdiction of UNRA. This continuous state of repair and upgrade poses a serious health hazard, and 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.

1.3 Geographical Information Technologies (GITs)

GITs are specialised ICTs that deal with the collection, management, storage and manipulation of georeferenced data. This is data that has geographical reference to the earth's surface. **Global Navigation Satellite System (GNSS)**, **Remote Sensing (RS)**, and GIS are the fundamental GITs on which this Thesis is based. GNSS is the standard generic term for satellite navigation systems that provide independent geo-spatial positioning with global coverage. Examples of GNSS include USA's Navigation Satellite Timing and Ranging System (NAVSTAR) commonly referred to as **Global Positioning Systems (GPS)**, Russia's Global'naya Navigatsionnaya Sputnikovaya Sistema (GLONASS), European Union's Galileo Systems, India's GNSS the IRNSS, and China's regional Beidou navigation system. The GNSS scope of this Research is limited to GPS.

GPS are space based navigation systems capable of performing in almost all weather. They were originally developed by the department of defence in the USA, to accurately define the position, velocity and time of events anywhere on or near the earth on a continuous basis. Their precise determination of location relies on the earth orbiting satellites and the ground location of the GPS receivers.

RS is a technology with the longest history among the three technologies and it has been defined in several ways in the literature. It is the science and or art of gathering and processing information about an area, object or phenomenon through the use of photogrammetric and satellite data acquired by devices such as aircrafts or satellites that are not in direct contact with the object area or phenomenon under investigation. RS usually relies upon measurements of electromagnetic energy reflected or emitted from the features of interest. This definition is combined from Lillesand and Kiefer (1994) and Campbell (1996).

GIS are systems that use a spatial database to answer questions to geographical related queries. It is a powerful set of tools for collecting, storing, retrieving at will, transforming and displaying spatial data from the real world for a particular set of purposes (Burrough and Mcdonnell, 1998). Its ability to define conditional queries, perform statistical analysis, create thematic maps and provide charting by allowing for better understand-ability of data gives GIS a superior status over its sister technologies.

More recently, it has become clear that GIS, together with GPS, aerial photography, RS 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 title of GIT (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 (Ehrensperger et al., 2007). 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).

Throughout this Thesis, GITs are considered to comprise of the technologies of GIS, RS (including photogrammetry and videography), and GPS, data/information & temporal attributes and the technical procedures or tools to process the data. The impact of GITs is always through the effectiveness of the GI, collected, produced and managed by these technologies, hence the incorporation of technologies, data and procedures in GITs.

1.3.1 GITs and Road Infrastructure Maintenance (RIM)

RIM is a prerequisite for the successful management of roads in the Country. This is because a well maintained road network as an asset is very important for the economic development of the Country. Even with the management of the highest possible quality of construction, maintenance is essential to get optimum service from the road structure during its life period (Office of the Auditor General, 2011). The understanding of GITs, effective use of GI and the knowledge of their advantages is critical to the planning and decision making process for road maintenance departments.

There are tremendous advances in GIT (Ehrensperger et al., 2007) to which Uganda's adaption is compelled. According to Ehrensperger et al. (2007), a wide range of GIS is available ranging from high cost server based to low cost user-friendly desktop software. Also, there is noted increase in the availability of spatial data. The spatial and temporal resolution of RS data has impressively increased, and more data are now freely available. The development of the Internet and web GIS have probably been the most outstanding advancements. These have 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

The use of GITs is also increasingly shifting from reference tools to dynamic decision making tools. When termed as reference tools, their use is limited for visualisation purposes. When dynamic however, the tools are actively used and involved in decision support. The demand for dynamic and multi-dimensional GIS is also rapidly increasing (Demirel, 2004). This shift has been triggered by, among other factors, emergency situations such as the World Trade Centre (WTC) attacks of September 11

200l (Kwan and Lee, 2005 and Harrison et al., 2007). This attack became a catalyst for change in the use of GITs for almost all relevant disciplines of which transportation is inclusive. As most of the data required for road maintenance is spatial in nature, GITs are quite relevant for this application. The spatial data, the basis on which road maintenance decisions are made can be gathered, analysed and updated continuously to allow near real time knowledge of the existing situation of roads. However, presently, besides the existing data on which decisions are based being neither comprehensive nor up to date, its use for decision making is limited to basic static reference tools. The submitted maintenance plans by the implementing agencies are likewise not comprehensive.

1.3.2 Trends in GIT Usage for RIM in Uganda

For some years, the development and use of GITs have been areas of activity in transportation agencies worldwide. In Uganda, focus has primarily been on the use of GIS for reporting events and accountability of road works to responsible government institutions and funding agencies. This is to say that GITs have been basically used as reference tools. Their use for data collection, integration and analysis has however not been common. The desire to use GIS by the MoWT in the management of the Districts, Urban and Community Access Roads (DUCAR) 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 management. Today, UNRA, which is charged with the management of national roads, also uses GIS for reporting. UNRA is at an advanced stage in 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, RAFU and now UNRA. In accordance with this policy and in order to improve the efficiency and effectiveness of its road network management, the Government of Uganda also decided to introduce an OPRC system. This system of performance-based contracting is designed to increase efficiency and effectiveness of road asset management and preservation. 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. Unfortunately though, this strategy is yet to take off as the procurement procedures among other issues are still challenges to get through.

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, the Road Agency Formulation Unit, 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 **Project Management and Engineering (PROME)** consultants' 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, odometer and a video camera mounted in the vehicle. It also possesses software to process the collected discrete data. The ROMDAS is basically used for inspection of the road network (Mihic and Ivetic, 2010). PROME is just one of the consultancy companies involved in road maintenance activities in the Country. Several other consultant and contractor companies without GITs knowledge and expertise are similarly involved in various road maintenance activities.

Decision to perform maintenance works on a road in Uganda, is initially based on; records of past expenditures on the road sections in question, availability of resources, traffic levels along these roads (these give an indication of the importance of the road), etc., all of which are not conclusive methods in predicting road maintenance requirements. It is important to reference the condition of roads with location, an aspect that GITs readily serve. However, there is marked underutilization of GITs in the decision making processes of RIM. Most of the data required for road maintenance is spatial in nature. As indicated by Luyimbazi (2007), road maintenance needs are based on road inventory, condition, and traffic data, all of which are informative only when referenced to the earth with locational attributes. This makes GITs relevant for the purpose of positioning the relevant data.

The focus of this Study is to devise strategies in the form of a framework for enhancing the use of GITs as decision support tools for RIM in Uganda, in support of the traditional method that is based on human judgment. This traditional approach has been used over time and in effect is a contribution to ad hoc road maintenance interventions. The HDM-4 (Highway Development and Management), is a famously used model in road management programs, also in Uganda. It is an economic valuation model and not a spatial decision making model. HDM-4 determines the optimal economic maintenance option, which maximizes the net benefit to society over the analysis period. The determining factor is mainly based on International Roughness Index (IRI) values of road sections.

1.4 Research Problem

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 its improvement. Maintenance attempts have extensively centred on fixing of potholes when observed. However, without use of appropriate data and data models for planning, road maintenance activities are bound to persist as costly and time consuming. As previously mentioned, advances in GIT use are tremendous world over, Uganda inclusive. However, there is no comprehensive methodology or framework for addressing both the technical and non-technical issues affecting GIT implementation in the road maintenance sector. The overall aim of this Research is to develop a framework to facilitate enhancing GIT use as decision support tools for RIM works in Uganda. It is in this respect that GITs can be employed to base preventive measures of road maintenance on reliable data.

The initiative to use GIS by road maintenance agencies in the Country is dominated by static reference products for graphical display. This is just one of the potentials of GIT use for various application domains. In reality, GITs are being underutilized for decision making in RIM processes. The focus of this Study is to unmask the use of geo spatial technologies as decision support tools for RIM in Uganda, as support to the traditional pattern matching and visual inspection (based on human judgement), that is currently predominant. The articulation by Bishop, et al. (2002, p. 313) that "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" says it all. Without such GIT interventions, the poor state of roads is likely to persist alongside the continuous state of repair that is health hazardous. The approach of pattern matching and visual inspection will likewise continue to constrain time and desolate both human and financial resources. This Research has developed a methodological framework towards enhancing the use of GITs in RIM for data collection, management and analysis in order to facilitate evidence based decision making. For this study, the term methodological framework is used to refer to a set of devised approaches that the road maintenance sector should adapt in order to enhance the use of GITs within the institution.

1.5 Research Objectives and Questions

The Research has been guided by a General Objective and three Specific Objectives.

General Objective: To develop a framework within which the use of Geographic Information Technologies can be enhanced as decision support tools for RIM in Uganda.

Specific Objectives:

1. To assess gaps in the use of Geographical Information Technologies for Road Infrastructure Maintenance in Uganda and the limitations to accessing these technologies.
2. To develop a methodological framework to enhance the use of Geographical Information Technologies as decision support tools for Road Infrastructure Maintenance in Uganda.
3. To develop a road maintenance data model for Uganda based on data requirements for Road Infrastructure Maintenance.

Research Questions:

Five (5) research questions were used to address the above specific objectives as follows:

Objective 1

i. Who are the actors in Road Infrastructure Maintenance and what are the barriers faced by Geographical Information Technology initiatives for Road Infrastructure Maintenance in Uganda?

ii. What potentialities and opportunities are foreseen in the use of Geographical Information Technologies for Road Infrastructure Maintenance?

Objective 2

iii. How can the use of Geographical Information Technologies 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?

Objective 3

iv. What is the nature of the data used for decision making in road maintenance and how effectively can it be represented in a GIS?

v. What is the most appropriate **Geographical Information Systems for Transportation (GIS-T)** data model for road maintenance in Uganda?

1.6 Scope

The Study was undertaken in Uganda, with Kampala and Jinja districts as the areas where fieldwork was performed. Kampala, being the capital City of the Country, and Jinja, because of its then poor road infrastructure and its sparse population that permitted effective field data collection, were selected for participation. The Research involved development of a methodological framework within which the use of GITs for RIM in Uganda should be enhanced. The framework is basically a methodological construction within which the organisations involved in the activities of road maintenance decision making can work together to boost the use of GITs.

Periodic road maintenance which involves preventive and corrective maintenance measures is the focus of this Research. This is the category of road maintenance that requires preplanning based on the condition aspects of the roads in question. This type of maintenance occurs periodically and in other circumstances arises out of emergent road conditions. All road maintenance initiatives that are based on road condition data however benefit from the findings and recommendations of this Study.

The GITs considered in the Study are limited to digital photography, videography, GPS, RS and GIS. A GIS-T road maintenance data model for Uganda was developed based on the road maintenance data requirements of the organisations involved. As most of the data is spatial in nature, emphasis was placed on the spatial data aspects. Some excerpts of the model were adapted from existing data models of countries with similar road maintenance data requirements. A sample of stakeholder organisations in the road maintenance sector was involved in development of both the methodological framework and data model.

1.7 Summary of Methodology

The Research was multifaceted and participatory in nature. It was participatory in the sense that stakeholders were involved in the Research during interviews, **Focus Group Discussions (FGD)**, observations, fieldwork activities, workshop and conferences.

Figure 1-1 shows the summary of the methodology including the methods used, the motivation for their use and the results accrued.

A review of literature was necessary at all stages of the Research hence the direct arrow from the literature review method to the motivation box. In the same sense, the facilitated workshop and the conferences attended contributed to the entire findings of the Research. Similarly, an understanding of GIT concepts and their applicability for road maintenance benefited all the results obtained. All methods employed in the Research had a contribution towards the framework to accentuate the use of GITs in the RIM sector. This explains the arrow from the motivation box to the hexagonal output indicating the developed framework. Available data from the identified stakeholder organisations was analyzed using various methods as is discussed in Chapter Three. This analysis together with the field observations & measurements fed into the identification of gaps and limitations to GIT usage, the framework to enhancing GITs in road maintenance activities, and the data model for road maintenance in Uganda.

1.8 Significance of the Research

The significance of the Research is highlighted in a couple of ways.

1. Presentations and publications composed of the research findings, recommendations and conclusions have been made to both the academia and the RIM sector.

2. It has created awareness of the potential of GITs for data collection, management and analysis both within the academia and among the stakeholders in the RIM sector. The Study has unwrapped research approaches to the academia. It has incited the sector 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 ICT in developing a global partnership to development. It should be appreciated that achieving global development is difficult unless initiated at a local level; road maintenance in this case satisfies this assertion.

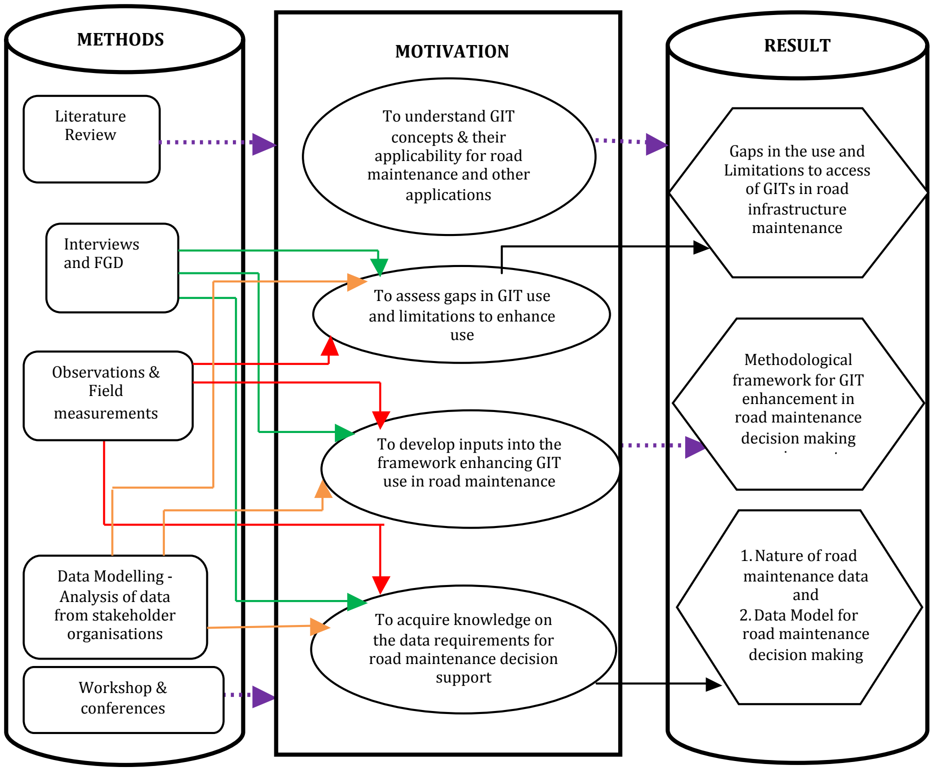

Figure 1-1: Summary of Methodology

3. The Research is well aligned with objective 5 of Uganda's NDP 2010/11-2014/15 which plan has since then substituted the Poverty Eradication Action Plan (PEAP). This objective endeavours to promote Science Technology and Innovation (STI) and ICT to enhance competitiveness. By showcasing innovative GIT notions within the academic and RIM sectors, the Research is addressing the key binding constraint of low application of Science and Technology. As has been ascertained, the transport network of a country plays a pivot role in the economic development of that country hence playing a part in its poverty eradication. Road maintenance strategies are aimed at maintaining and improving the state of the transport network infrastructure.

4. The Research has also assessed the gaps and limitations that are affecting the usage of GITs in the road maintenance sector. These gaps and limitations have been discoursed with the academic world thus creating a focus for research on how to address them. Their documentation is also an opening for the responsible offices to deal with the challenges. Notice that even though the Research is dealing with the road maintenance sector, these gaps and limitations are affecting several other sectors that make use of spatial data for decision support. Documenting these challenges is a prospect to having them addressed either through further specific research or at sector levels.

5. The framework as one of the outputs of this Research builds from this research findings, theories and concepts from previous researchers hence a contribution to a whole body of knowledge. It is a guideline to the sector on how to enhance the use of GITs in support for knowledge based decision making. The framework components and strategies are pointers to further research.

6. Finally, the Research proposes a GIS-T data model for RIM in Uganda. The model is a contribution to standardising data for GIS-T use and is intended for all organisations with a stake in mainly periodic road maintenance that is dependent on road condition data.

1.9 Structure of the Thesis

The Thesis comprises of 8 chapters which have been logically presented to get across the chorological flow of the accomplished Research. The structure is made elaborate in Figure 1-2.

Chapter One is the general introduction where the background of the research is presented. The research problem, objectives, research questions and a summarised methodology are highlighted. Within this chapter, a summary of all the chapters is given for further guidance on reading the Thesis.

Chapter Two gives an overview of the conceptual terms and definitions as used in the research. It is basically the contextualisation of the research that attempts to relate road maintenance and GIT concepts.

Chapter Three presents a review of GITs for road maintenance and other related applications. It is a further contextualisation of the research in terms of previous research attempts in the related theme 'GITs for road maintenance'.

Chapter Four: Methodology, discusses the adopted methodology. It explains how the various research methods were used to obtain data and their analysis.

Chapters five, six and seven are results oriented.

Chapter Five presents the results of the qualitative and GIS analysis in relation to the research questions. The gaps, limitations and potentials of GITs in road maintenance are presented and discussed.

Chapter Six is a documentation of the methodological framework for the accentuation of GITs in road maintenance.

Chapter Seven presents the GIS-T data model for road maintenance in Uganda. For purposes of a more effective flow and understanding of the model, some concepts relevant to data modelling, not discussed in Chapter Two, are introduced in Chapter Seven.

Chapter Eight concludes the Thesis and contains the overall research conclusions and recommendation.

Throughout the Thesis, when reference is made to this Thesis, Research, & or Study and to various Chapters and Sections within, the first letters of the referenced particulars are capitalised.

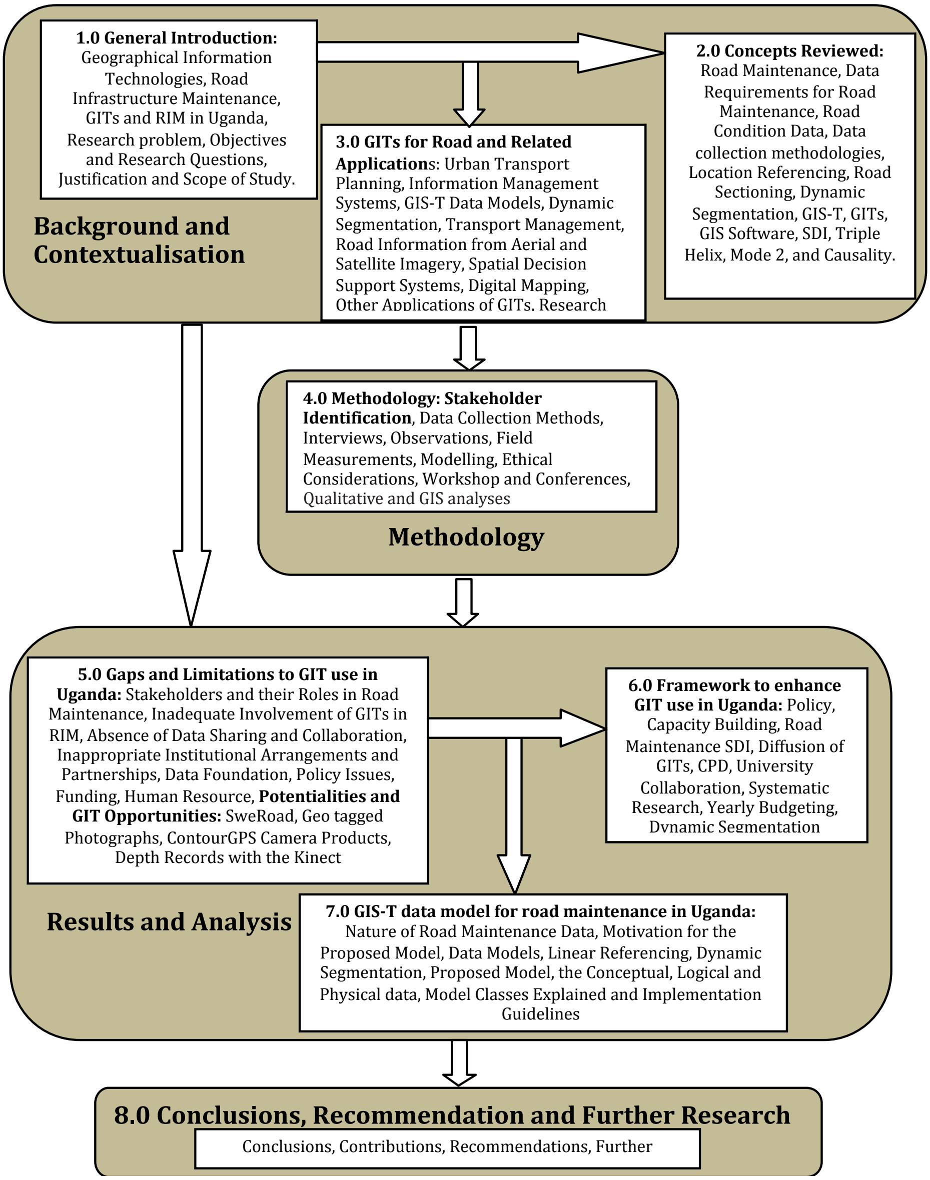

Figure 1-2: Structure of the Thesis

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CHAPTER TWO
OVERVIEW OF CONCEPTUAL TERMS AND DEFINITIONS

2.1 Introduction

This Chapter is a review of the conceptual terms and definitions pertaining to road maintenance, GITs, and methodological concepts used in this Thesis. Road maintenance is defined and its scope streamlined for the Study. Some definitions of operational terms are established and the requirement, collection and indexing of road maintenance data is presented. The basics of location referencing comprising of linear and spatial referencing are presented and differentiated in terms of their use and importance for road maintenance. Data and section based sectioning of the road is illustrated with emphasis on **Dynamic Segmentation (Dynseg)** which is a particularly important concept in applying GIS and related technologies to the field of transportation. The GIS-T concept is explained, GITs are discussed and an overview of GIS software is given. The concepts of **Spatial Data Infrastructure (SDI)** and the principle of causation are reviewed as basis on which the presentation on gaps and limitations in GITs use for road maintenance is made. Lastly, 'mode 2' knowledge production - the contemporary way of producing and co-producing scientific knowledge, is presented. Triple helix is cited as an example of implementing the 'mode 2' transdisciplinary knowledge production.

2.2 Definition and Scope of Road Maintenance

Road maintenance encompasses a wide range of activities, an understanding of which is vital for pursuing this Thesis write up. The point of intervention on a road in a bid to perform maintenance works is quite important and determines the type of maintenance activity to be undertaken. Paterson (1993) defines maintenance in general as the combination of all technical and associated administrative actions intended to retain an item in, or restore it to, a state in which it can perform its required function. **Road maintenance** therefore embodies both the technical and administrative actions by the responsible persons to retain or restore the road in the state in which it can perform its function (Rommert, 1996). The basic objective of road maintenance in Uganda is to ensure that the road constructed, or improved, is maintained in its original condition as much as possible (Office of the Auditor General, 2011). Road maintenance is divided into two main categories - Routine and Periodic Maintenance.

Routine Maintenance involves works that are undertaken throughout the year. They are usually funded from the recurrent budgets of the country. Today however, several countries have established road funds to finance maintenance activities. The operation of the **Uganda Road Fund (URF)** is discussed in Chapter Five. Activities under routine work are either cyclic or reactive. Cyclic works are those performed according to the frequency as dictated by the maintenance standard. They are dependent on effects from the environment like drainage and over grown hedges. They include culvert cleaning and edge cuttings. Reactive works on the other hand are those dictated by intervention levels as defined by the maintenance standards. For instance, the variation of traffic levels is a primary cause for reactive routine maintenance. The most obvious example is the sealing or patching of potholes or cracks as they appear on roads. Routine maintenance involves activities aimed at ensuring safe and regular flow of traffic and these are often given the highest priority (Office of the Auditor General, 2011) in Uganda. This maintenance category provides for the regular or normal highway maintenance work such as cleaning, patching, strengthening and all the minor repairs of highway features, upholding the daily housekeeping type maintenance services. It does not provide for major repairs, or those services that are normally considered to be betterment.

Periodic Maintenance involves those activities that are intended to keep up the standard of the road and to prevent its continued deterioration. These are works undertaken approximately every 3-5 years and require an inventory of road condition to base implementation and funding mechanisms. Due to the expense attributed to data collection for road maintenance decision making, this period is often 5 years in Uganda. Periodic maintenance involves the rectification of defects which are outside the scope of routine maintenance. The major groupings under periodic maintenance are preventive, corrective, and pavement reconstruction. Resurfacing and overlay are typical examples of periodic maintenance implementation chores. In principle, these works exclude those activities that change the geometry of the road by widening and realignment which fall under rehabilitation.

In **Federal Highway Administration, FHWA**, (1999), the American Association of State Highway and Transportation Officials (AASHTO), define **preventive maintenance** as an activity under pavement preservation. It is "a planned strategy of cost-effective treatments to an existing roadway system and its appurtenances that preserves the system, retards future deterioration, and maintains or improves the functional conditions of the system without increasing structural capacity" (ibid, p. 4). Preventive maintenance extends the life of a pavement while offering satisfaction to the community. Unlike corrective maintenance which reacts to failures on the road, preventive maintenance advocates for doing the right treatment to the road at the right time.

Throughout this Thesis, the term maintenance is used to refer largely to periodic maintenance in particular both preventive and corrective road maintenance. Preventive maintenance is that category of maintenance that is based on a planned strategy of which data/information is a basic requirement. **Corrective maintenance** on the other hand is also accomplished based on road condition inventories and sometimes on emergent reports from a variety of stakeholders (Government and road users) on the state of certain roads. Some road maintenance aspects and data requirements referred to in the Thesis, however, encompass the whole body of routine and periodic works but this shouldn't create confusion to the reader. Preventive and corrective maintenance are mainly earmarked to create a focus for the Study. Periodic maintenance contracts may be implemented and utilised to correct any observed or anticipated highway feature deficiency. The terms observed and anticipated in this case imply the requirement for specific datasets to warrant maintenance intervention. When observed, the highway feature deficiency will undergo corrective maintenance, and when anticipated, preventive maintenance suffices. Periodic maintenance includes major repair accomplishes and/ or reconstruction of highway features or facilities. For example, it may necessitate to resurface a section of highway and to relocate other sections. New guardrails may be installed or damaged culverts may be replaced as part of a periodic maintenance contract.

Depending on the intervention level, rehabilitation can also be a category of road maintenance. It involves removal of the road surface and restoration of the original slope and natural drainage patterns to prevent erosion and re-establish site productivity. Hall et al., (2001) define **pavement rehabilitation** as a structural or functional enhancement of a pavement which produces a substantial extension in service life, by substantially improving pavement condition and ride quality. The prime difference between rehabilitation and maintenance is that rehabilitation extends the service life of the road whereas maintenance preserves the condition, safety and ride quality hence aiding the pavement in achieving its design life (ibid). By virtue of its intended objective, preventive maintenance is also known to extend the pavement life of a road, the reason this Thesis likens rehabilitation to maintenance.

2.3 Operational Definitions of Some Terms

Road maintenance managers make use of a number of systems in the execution of their tasks. These include but are not limited to; bridge maintenance systems, network referencing systems, GIS and pavement management systems. Many of these systems are independent but may in some circumstances be informative of each other. The terms defined here below are applied to GIS. They may or may not be common between the various systems.

Transportation Feature: is an identifiable element on the transportation system (Dueker and Butler, 2000) which can be a point, line or area. Examples include roads, railways, bridges, and airports. Some transportation features can contain other features like roads contain bridges. When this is the case, the contained feature would be defined by a linear location referencing system (see Section 2.5.1).

Road: A road is a route or way, paved or otherwise improved, on land between places intended for vehicles. It is in contrast with a shoulder or sidewalk but may encompass all.

Node: is a logical point, a zero dimension object on the physical road network often defined by intersections of surveyed centrelines. The intersections include connections of links (see link definition below), major road junctions, roundabouts, and other points at which there is a significant change in traffic, carriageway characteristics, or administrative boundaries e.g. station & region locations (Kerali, 2000). Nodes also include reference marker points from which field measurements can be made. Important features like jurisdictional boundaries, intersections, bridge abutments and beginning of projects are often identified as nodes (Dueker and Vrana, 1992) in a GIS.

Reference Marker Points: these are points from which linear referencing of the road network can be established. They can be fixed identifiable points that are either physical objects, natural features, or can be logically defined, with or without a relationship with the length of the road, but are defined from surveying beacons.

Road Section: Sections are road segments between defined nodes such as reference markers along the road. Kerali (2000) defines sections as lengths of road over which physical characteristics are reasonably constant. Sections relate to an underlying set of linear spatial objects (Dueker and Vrana, 1992) where the start and end may be defined by two nodes.

Route: A route is a logical ordered set of sections. Routes are collections of sections which may belong to more than one route (ibid). Note, that in the latter chapters, the terms road and route are used synonymously/interchangeably in road maintenance.

Link: Links are one dimensional logical connection between nodes on the transportation network. They are line sections between two defined nodes. Kerali (2000) defines links as one or more sections over which traffic is reasonably constant. For purposes of this Thesis however, a link is a section of a road defined by two nodes. Whether the two nodes are indicating sections of constant traffic or road condition is a matter of the recipient. A road section can be composed of several links.

Road Pavement: This is the road way of a paved/sealed road on which vehicles drive. The term 'Road Surface' is used in the same sense as road pavement when referring to an unsealed road. In more engineering vocabulary, the term carriageway may also be used to refer to either the road pavement or road surface.

Point Features: These are features which are defined by points along the road. They include accident locations, signs posts, culverts, bridges, etc. as may be located on the road.

Linear Features: These are features defined by lines along the road. They are linear objects on the transportation network that have a defined start and end point. Linear features are lengths of road having a homogenous characteristic, such as a constant pavement width, roughness value, condition or surface type (Dueker and Vrana, 1992).

Events: Events are attributes on the transportation feature that describe either a single location or portion of it. They are tangible elements/ physical components or intangible characteristic occurrences on the transportation feature. When referring to a single point on the transportation feature, the term **point event** is used and in reference to a portion, **linear event** is used.

Topology: Topology is one of the two main components of spatial information. The other is geometry. These two components are often unclearly handled. Whereas **geometry** refers to the dimensions of the spatial element under study, topology is the geometrical relationships between these spatial objects. Topology is considered the logical abstraction of geometry (Demirel, 2002) that deals with order, connectivity and adjacency. It is the spatial relationships between geographic features e.g. containment, and proximity, enabling advanced spatial analysis and playing a fundamental role in ensuring the quality of a GIS database.

2.4 Data Requirements for Road Maintenance

A lot of data pertaining to the condition of the road is required for planning and monitoring of the activities included in the efficient and effective execution of road maintenance operations. Paterson and Scullion (1990) indicate that one of the 2 principle inputs to effective road management is appropriate and up to date information to support management decisions. The other input being well defined objectives as stated in a policy framework document. Paterson and Scullion (1990) have suggested a couple of information groups to guide data collection for road management purposes. Table 2-1 indicates these groupings. Although refereeing to the broad aspect of road management, these grouping suffice for road maintenance too.

Table 2-1: Road Management Data

Element	Aspects
Road Inventory	Network/Location Geometry Furniture/appurtenances, environs
Pavement	Pavement structure Pavement condition
Structures	Structures inventory Structures condition
Traffic	Volume, Loadings, accidents
Finance	Cost, Budget, Revenue
Activity	Projects, Interventions, commitments
Resources	Personnel, Materials, Equipment

Source: Paterson and Scullion (1990)

Inventory data often refers to the physical elements of the system that do not change markedly over time. They are typically measured in one off exercises and updated as and when changes occur. Condition data on the other hand changes over time and it requires regular or irregular monitoring. Besides inventory datasets, this Research is mainly concerned with the pavement condition data, the basis on which road maintenance decision is made. There is a wide range of technologies available to the road manager for measuring the required attributes of the condition of the road network. However, these depend on the **Information Quality Level (IQL)** required for these data.

IQL correlates to the degree of sophistication of the data combined with the required methods of collecting and processing it for decision making. The higher the decision level, the higher the IQL. For policy making at the highest decision making level, for example, IQL-5 data is recommended. Low-level data (IQL-1) for example can be condensed or aggregated into progressively simpler forms to become higher-level data (IQL-5). Bennett et al. (2007) have defined five levels of IQL-data for general use. These levels are diagrammatically represented in Figure 2-1.

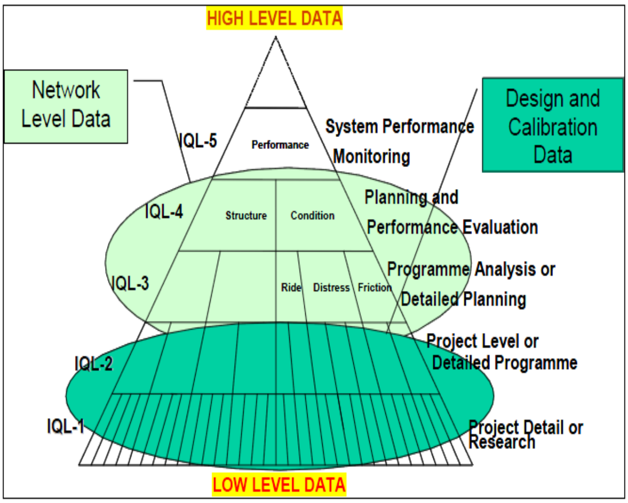

Figure 2-1: Information Quality Level (IQL) Concept
Source: Bennett et al. (2007)

IQL-1 represents fundamental, research, laboratory, theoretical, or electronic data types, where numerous attributes are measured.
IQL-2 represents a typical level of detail of engineering analyses for project-level decisions.
IQL-3 represents typically two or three attributes, used for network-level surveys or where simpler data collection methods are appropriate.
IQL-4 is a key attribute used in planning, senior management reports, or in low technology data collection.
IQL-5 represents top level data such as key performance indicators, which combine key attributes from several pieces of information.

2.4.1 Road Condition Data

The condition of the road guides the decision maker as to where, when and what works to perform on the road as the maintenance strategy. It gives an indication on which road sections should have more priority over others. Several variables and indices exist to describe the state of the pavement surface. The pavement characteristics (some of which are variables and others indices) considered in an evaluation include roughness, texture, skid resistance, mechanical/structural properties, and, surface distress. These characteristics are measured using either visual inspections or specialized equipment in the field. They are then quantified by means of indicators or condition indices. For example, rut depth, cracking and faulting are indicators corresponding to local visually defined conditions, while ride number, **Pavement Condition Index (PCI)**, and the **International Roughness Index (IRI)** are computed indices for a segment of road. Table 2-2 is a summary of the pavement characteristics, examples of the condition indicators and indices and the basic equipment for their measurement. The evaluation type gives an indication of why that pavement characteristic is assessed.

Table 2-2: Pavement Functions and Characteristics by Evaluation Type

Evaluation Type	Pavement Function	Pavement Characteristics	Examples of indicators and indices	Equipment
Functional evaluation	Serviceability	Roughness	IRI	Laser and manual methods for precision profiles, IRI estimates from correlations, subjective ratings
			PSI	
			QI	
	Safety	Texture	Macro texture	Static and manual equipment
			Micro texture	
		Skid Resistance	Skid resistance coefficient	
			IFI	
Structural evaluation	Structural capacity	Mechanical properties	Deflections	FWD, deflection beams, DCP, lab tests
		Pavement distress	cracking	Video distress analysis, visual surveys, transverse profilers
			Surface defects	
			Profile deformations	
Referencing system		Characteristic data- location of pavement		GPS, video logging

Source: Adapted from Bennett et al., (2007) The IRI is a standardized roughness measurement calculated using a mathematical simulation of a quarter-car (i.e., a single wheel) travelling along the road profile at a speed of between 50-80 km/hr depending on the agency conducting the measurement. It summarizes the surface characteristics that impact vehicle response and describes profile roughness that causes vehicle vibrations. It can therefore be viewed as the amount of vibration, or vertical acceleration experienced by a driver of a vehicle travelling along the said road at a highway speed (Kennedy et al., 2000). The IRI is defined as a characteristic of the longitudinal profile of a travelled wheel track with units of metres per kilometre (m/km) (Cumbaa, 1990) as cited by Kennedy et al., (2000). The closer to zero (0) the value of IRI the smoother the road is. Depending on the highway class, an IRI of more than 3 often leads to rehabilitation of the road.

The **Present Serviceability Index (PSI)** was a prior objective quantitative index to evaluate pavement roughness. It superseded the first qualitative pavement roughness rating system that gave the evaluation in a term known as the **Present Serviceability Rating (PSR)**. **The Quarter Index (QI)** is related to the IRI and is given in metres per kilometre (m/km). **The International Friction Index (IFI)** on the other hand gives a correlation of texture and skid resistance measures.

There exist two categories of road surface types, paved and unpaved roads. A paved road is defined as any road that has a semi-permanent surface placed on it such as asphalt, concrete, and setts or cobblestones. Gravel surfaced roads are virtually always referred to as unpaved roads. In Uganda, majority of the roads are unpaved. The distress characteristics for each of the surface types differ to some extent. The PCI for a paved road and **Unsurfaced Road Condition Index (URCI)** for an unpaved road (Technical Manual, 1995) is a numerical single general road performance indicator. The scale ranges between 0 and 100 and the higher the value the better the condition of the road. It indicates the road's integrity and surface operational condition. It is often based on distress surveys which provide information on the various distress types, their locations, severity, and extent.

Road condition can be monitored through condition indices or measured through road surface distresses. The indices, in most cases, are not directly related to specific maintenance treatments like the surface distresses are. Often, indices are used to communicate IQL-5 data. Otherwise, for actual maintenance planning strategies and implementation, road surface distresses are used. The surface condition rating is done according to the surface condition rating manuals that ensure the high quality of collected data and measurement procedures (Zvjezdan, 2003).The data indicators can be either numeric or descriptive. The descriptive indicators are often visually assessed and guidelines to these assessments are documented fostering both data collection and use. Table 2-3 is an example of the visual rating guidelines from PROME Consultants Uganda which was used for the national roads inventory data collection. The descriptive indicators are often coded for storage in the database. If necessary, a row for comments is used to describe the indicator further.

Table 2-3: Visual Rating Guidelines

Visual Rating Guidelines						
ID	**Visual Defect**	**1**	**2**	**3**	**4**	**5**
1	All Cracking	0%	>0% and <5%%	>=5% and <15%	>=15% and <30%	>=30%
2	Wide Cracking	0%	>0% and <10%	>=10% and <25%	>=25% and <50%	>=50%
4	Width Loss	0mm	>0mm and <50mm	>=50mm and <150mm	>=150mm and <250mm	>=250mm
5	Edge Drop	0mm	>0mm and <50mm	>=50mm and <100mm	>=100mm and <150mm	>=150mm
6	Ravelling	0%	>0% and <5%	>=5% and <15%	>=15% and <30%	>=30%
7	Rutting (Paved)	0mm	>0mm and <5mm	>=5mm and <10mm	>=10mm and <20mm	>=20mm
8	Roadside Friction	None	NOT USED	Moderate	NOT USED	Significant
9	Potholes (Unpaved)	0%	>0% and <1%	>=1% and <3%	>=3% and <10%	>=10%
10	Gravel Thickness	>=150mm	>=100mm and <150mm	>=50mm and <100mm	<50mm	0mm
11	Rutting (Unpaved)	0mm	>0mm and <10mm	>=10mm and <30mm	>=30 and <60mm	>=60mm
12	Corrugations	1	2	3	4	5
	1. No Corrugations 2. Can be felt and heard; No speed reduction necessary 3. Can be felt and heard; Speed reduction necessary 4. Significant speed reduction necessary 5. Drivers select a different path and drive very slowly; Safety is affected					
13	Formation Level	1	2	3	4	5
	1. Well above ground level; Edges of road are at least 600mm above bottom of ditch 2. Slightly above ground level; Road is >=300mm and <600 mm above bottom of ditch 3. Drainage is level with road surface; Road is generally at ground level with ineffective side drains; Storm water could cross in most places 4. Isolated areas of the road are below natural ground level; No side drains are present and localised ponding of water will occur 5. Road is the lowest point and serves as drain for the entire area					
14	Drainage Condition	1	2	3	4	5
	1. Clear no visible obstacles 2. Generally clear with a few obstacles 3. Slightly overgrown with some obstacles 4. Partly blocked, depth of drainage less than designed due to siltage 5. Blocked, eroded and not functioning as drainage					
15	Erosion Gullies	1	2	3	4	5
	1. No erosion gullies; Camber intact or insignificantly affected by rutting; Signs of erosion or sedimentation for less than 10% of road length 2. Not used 3. Ruts show clear signs of erosion (gullies) or sedimentation by flows along the alignment for >=10% and <30% of road length; Occasional diversion of longitudinal flow to side drains or terrain 4. Not used					

Visual Rating Guidelines						
ID	**Visual Defect**	**1**	**2**	**3**	**4**	**5**
	5. Ruts show heavy erosion (gullies) or sedimentation by flows along the alignment for more than >=30% of road length; Minor erosion gulley meanders from rut to rut and occasionally from ditch to ditch; Major erosion gulley may have developed along ditches					
16	Roughness	1	2	3	4	5
	1. Ride very smooth and very comfortable; No/slight unevenness of the profile; No rutting or potholes; IRI value <5 2. Ride smooth/fair and comfortable; Moderate unevenness of the profile; Moderate rutting but no potholes; IRI value >=5 and <7 3. Ride poor and uncomfortable; Frequent unevenness of the profile; Significant rutting, corrugations and occasional potholes; Moderate speed reduction; IRI value >= 7 and <9 4. Ride very poor and very uncomfortable; Severe unevenness of the profile; Extensive rutting, corrugations and severe potholes; Driving speed much lower than speed limit; Road unsafe owing severe unevenness; IRI value >=9 and <16 5. Impassable except by 4WD. IRI value >=16					

Source: PROME Consults, Uganda 2009

2.4.2 Data Collection

Collection of the various road condition data is achieved either by using an automated data collection system or by manually rating the road network (Zvjezdan, 2003). The automated data collection systems usually consist of three subsystems; the longitudinal profiling, transverse profiling and digital video distress collection subsystem. The transverse and digital video distress collection subsystems may as well have GITs embedded. An example is the ROMDAS (ROMDAS, 2010) that is also already in use in Uganda. The ROMDAS is a low-cost and flexible data capture technology that 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 various surveys e.g. roughness, travel time, congestion, condition ratting, inventory, moving traffic, transverse profile/rutting, and video logging surveys. It is also possible to collect GPS data, record the location of digital photographs, and create voice records which are associated with road attributes (Sodikov et al., 2005).This collected data is often post processed and stored in centralized databases from where it can be accessed and used for decision making.

Road distress surveys as is a requirement for planning and design of road maintenance projects are traditionally based on extensive field observations by trained experts. They provide information on the various distress types, their location, severity and extent (Miller and Bellinger, 2003) as cited in Herold et al. (2004). These surveys are accomplished by evaluating existing pavement condition considering a variety of distress types and aggregate the information into a PCI. This index is derived by trained and experienced personnel following documented guidelines based on the type, extent and severity of pavement distress.

“Roads are prioritized for maintenance and treatment as a result of pavement inspections. The cost of frequent, comprehensive inspection is high, and many jurisdictions limit their immediate surveys to major roads, with minor roads surveyed in 3-year cycles" (Herold et al., 2004, p.1). This has an effect on the maintenance decisions made at the end of the day. For this purpose, a number of survey technologies have been explored for road condition mapping. The common practice today is extensive field observations by experts who characterize the PCI, based on established physical parameters such as cracking, rutting, raveling, etc. (ibid). Other technologies have evolved such as the application of Pavement Management Systems (PMS); typically coupled with GPS/GIS technology and semi-automated in-situ pavement health surveys facilitated by vans (ibid). In Uganda for example, the ROMDAS prior described is used for national roads survey. It captures exhaustive photographic and video logs of pavement quality (and at the same time asset inventory), while recording road geometry with GPS and Distance Measuring Instruments (DMI). From these data, a detailed and georeferenced condition report, with PCI ratings for sections of the road can be produced (ibid). Nevertheless, this remains an expensive and troublesome survey and yet cost and safety considerations require that it be done at regular intervals. Various literature, as documented in Chapter Three have led to research of recent advances in hyperspectral RS technology to aid in data collection. Currently emerging technologies in this context are observations from Unmanned Airborne Vehicles (UAV). This Research attempted a similar innovation with a survey using a low flying paramotor. This however failed due to failure to secure flight permission from the Civil Aviation Authority (CAA) of Uganda (see Appendix 3).

2.5 Location Referencing

For decision making relevant to road maintenance, the road condition data should refer to specific points or sections along the road. Reference to these points and sections is a prerequisite for planning strategies to undertake the actual maintenance. Since roads are geographically placed, geographical reference to these locations is paramount. Equally important and fundamental is the geographical location of the entire road in consideration, this within the jurisdiction context. "Location referencing is the singularly most important consideration in conducting a survey. Unless the data are properly referenced, they will be of limited use in making management decisions." (Bennett et al., 2006, p.2; 2007, p. 12).For instance, the thickness of gravel on an unpaved road is not uniform throughout the road. It varies from section to section. Likewise, the roughness, rutting and friction vary between road sections. Potholes also exist at specific locations along the road. Similarly, maintenance strategies are not communicated for the whole length of the road. Condition is stated on a point or section basis. This therefore necessitates a means to locate these point and linear sections of particular condition that require maintenance priority. Location referencing is thus a very important aspect of road maintenance systems. It enables the user to precisely locate an object along the road and correctly reference the objects to each other in the database, (**HTC Infrastructure Management Ltd (HTC)** (HTC, 2002)). There are majorly two ways of referring to the location of features on the road network - linear and spatial location referencing. For a more grounded understand-ability of location referencing, the difference between Location Referencing Method (LRM) and Location Referencing System (LRS) needs to be clearly articulated.

2.5.1 Location Referencing Method (LRM) and Location Referencing System (LRS)

LRM is the technique used to identify the specific point or object location of road, either in the field or office. It is a mechanism for finding and stating the location of an unknown point along a network by referencing it to a known point. On the other hand, LRS is the total set of procedures for determining and retaining a record of specific points or objects along the road. LRSs support the storage and maintenance of information on events that occur within a transportation network (Miller and Shaw, 2000). This system may consist of one or more LRM(s). The LRS is the basis on which road condition data is collected from the field and referenced to the road network in the database. It consists of the transportation network, the LRM(s) together with the procedures for storing, maintaining, and retrieving the information about points and segments on the road and the datum. The datum is the set of objects with known (directly measured) georeferenced locations that connect the LRS to the real world. It is a set of parameters and control points used to accurately define the three-dimensional shape of the earth (Smith et al., 2001). It is the basis for a planar coordinate system and a reference surface for horizontal and vertical earth measurements. Georeferenced locations are those locations that have a reference to the earth's surface. These are points with known geographic coordinates. It is the datum that supports the integration of other networks, LRMs and cartographic display of the transportation network data.

2.5.2 Linear Referencing

Linear referencing is a method that is widely used by transportation agencies to record position information along linear features (Nyerges, 1990 and Vonderohe et al., 1998). It locates information on a linear feature using a single relative position on the feature by giving an address consisting of a distance and direction from a known point location. Linear referencing is the process of identifying location(s) on a network or specific link in a network by specifying a start position, direction and distance (Smith et al., 2001). The underlying datum for linear referencing is the network and not the coordinate system for spatial referencing. Various methods for linear referencing exist, for example, location can be given in terms of:

- Kilometre point method - kilometre distance measured from the start of the road,
- Kilometre post method - measures from a physical km post,
- Reference point method - distance from known physical reference object along the road,
- Reference post method - distance from well-established reference posts, and
- Link node method.

The link node method is a special implementation of the generic referencing system. The nodes refer to specific locations on the roads and the links are sections between the nodes. It is a special application of the reference point method where permanent features e.g. bridges, intersections, road junctions, etc. are given node numbers. Roads are then collections of adjacent links. Any referencing method can thus be applied with a link-node system. Kennedy et al. (2000) assert that a method for linear referencing is the basic foundation for road applications especially if GIS integration is involved.

The choice of which method to use varies between countries basing on the nature of the network and the local needs in existence for each country. Each of the methods however has its own advantages and disadvantages. An effective linear referencing method should however; be easy to understand and implement, bear no need for reference post maintenance, be cheap to establish, and enable the public to make use of it when needed.

2.5.3 Spatial Referencing

Under spatial referencing, the position of reference points and sections on the road is expressed in terms of a set of spatial coordinates. There are tremendous advances in GITs that necessitate the collection and use of spatial data for decision making. GPS data is commonly used to spatially reference roads and other linear network objects. Dynamic linking of the spatial and linear reference methods should therefore become essential in the road information system. Even though many of the road condition attributes require a position which can be spatially referenced, HTC (2002) asserts that the basic rule for GPS referencing should be that "only those data which are most suited to spatial referencing should be spatially referenced" (ibid, p.21). In principle, spatial referencing should not take over linear referencing. This is because two-dimension coordinates are hard to obtain and hard to match with maps (Zhu and Jiang, 2009). But, since the transportation network is linear, the linear distance from a known point, as one dimensional reference method is suffice. This distance may be stored as attribute information on road sections and points for adoption as the method of reference. Spatial referencing is generally required for reference stations and other key referencing features such as, the road centreline, off road objects, for example signposts, which cannot be referenced using displacements and offsets (HTC, 2002). Other emergent road features that may need to be communicated for ease of location either as reports of critical road condition like very big potholes or as events during the implementation of road maintenance works may also be spatially referenced. These however also need linear locational reference for complementarity and inclusion into the robust information management system.

In advanced environments, location referencing is achieved using digital DMI for linear referencing, and GPS receivers for spatial referencing. Video logging is included in location referencing as it is commonly used to determine the position of objects. In most circumstances, it is used for more than just referencing (Bennett et al., 2006, p. 2). In Uganda, PROME consults has used video logging to carry out road condition inventory surveys. These video logs are used for estimating missing data in situations where a percentage of inventory data is wanting on a road section.

Table 2-4 presents some examples of location referencing equipment.

Table 2-4: Location Referencing Equipment

Location Referencing Equipment	
Digital DMI	Conventional digital DMI
	Digital DMI integrated with other data
GPS	Portable GPS
	GPS integrated with inertial systems
Video Logging	Analog imaging
	Digital imaging

Source: Bennett et al., (2006)

2.6 Sectioning

As mentioned in the above section, the road condition is given per point or section for easier management and reference by the responsible personnel. Two types of sectioning exist. Data based sectioning and section based sectioning. Section based sectioning is the breaking of the roads into the smallest denominator sections (HTC, 2002) based on predefined criteria. This criterion is for example composed of presence of junctions, changes in condition, surface types and limit on the lengths of the section. The commonest approach in Uganda is to create sections between sequential roundabouts, road junctions, and intersections. The aim is to ease reference to road events and in the long run, for effective road management of section by section. In some circumstances however, sections are created based on the homogeneity of the road e.g. sections of uniform condition or uniform surface material. In effect, paved and unpaved roads are often segmented differently. As the basis of sectioning is ease of management and reference to road events, the predefined criteria is managed by the experts during sectioning. In effect, road sectioning is subjective and varies from organisation to organisation. In Uganda, it is said that there is a limit to the length of a section. This raises an issue when the limit falls before the next predefined junction or roundabout.

Data based sectioning as the name suggests is sectioning that is based on the available data during analysis. This type of sectioning allows the user to re-break the road into segments based on data that are prior collected from the field. Referencing and data processing of the newly created sections should be done automatically basing on the other referenced data tables. During analysis of road condition data for instance, when condition attributes change between points, segments are created. For example, homogenous segments can be created from roughness and rutting data on the road so that as roughness and rutting values change, new segments are created basing on the new roughness value identified. Figure 2-2 is an illustration of the data based type of sectioning. Note the analysis segments that have been created from roughness and rutting data sections. This Research has adapted the terminology 'segment' to refer to sections that are defined out of data based sectioning.

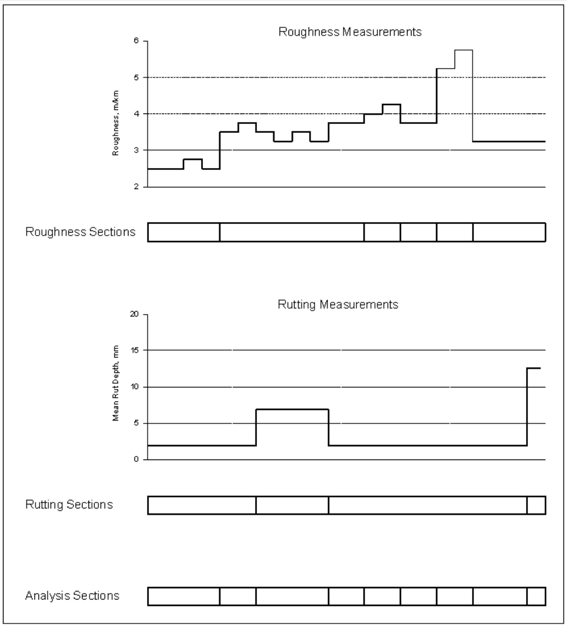

Figure 2-2: Data Based Sectioning Illustrated
Source: HTC (2002)

2.6.1 Dynamic Segmentation (Dynseg)

Pavement management systems require accurate methods of developing priorities and assessing conditions (Kennedy et al., 2000). In order to make proper management decisions regarding road maintenance, the pavement condition data must be summarized into homogenous lengths to aid prioritisation of implementation works. Applying a segmentation procedure to produce uniform and consistent segments can greatly enhance the usefulness of the road condition data (ibid). "A road network's attributes are analysed and analysis segments are created based on these attributes. Since attributes such as roughness can change from year-to-year, the segments will also change from year to year" (Bennett et al., 2007, p.8). Dynseg a technique that involves a combination of multiple sets of values to any portion of a linear feature based upon trends in the data (Kennedy et al., 2000), is best suited for this purpose. It is a method for segmenting a road network into segments without physically breaking the links and adding nodes (Chou et al., 2002). Linear data are instead stored with 'from' and 'to' linear distance points such that thematic maps are created basing on this linear distance attribute data. In effect, any changes to the linear attribute data do not require changes to the underlying road network. The motivation is to aid visualisation of road segments based on selected attributes. Dynseg uses linear location referencing methods to dynamically segment roads based on the condition attribute values of points and sections along the road. The main advantage with dynseg is that the geometry of the road remains unchanged while different views of road condition are being analysed for maintenance action.

Dynseg offers a solution to managing linear data in a GIS as its primary purpose is to create point and linear spatial objects when needed (Dueker and Vrana, 1992). Fundamental principles concerning attribute and spatial data handling requirements for linear spatial objects are revealed by the dynseg concept (ibid). It is a classic GIS tool for analysis of roads, pipelines and railroads used in transportation and utility network applications (Goodman, 2001). The dynseg process generates point or linear geometry for database record events that are referenced by their position along a linear feature allowing the information originally stored in a tabular report to be visualized on a map, displayed, queried and analysed in a GIS (ibid). The general dynseg process involves 2 steps, first, the creation of a route and secondly the association of events to the route system using their measures. Dynseg is commonly viewed as one of the most effective aspects of GIS for transportation applications (Huang, 2003 and Huang and Yao, 2003).

From the background discussion of data based sectioning, dynseg can be defined as a process of transforming the data available in different sets of sections to a target section (HTC, 2002). The process of dynseg is exemplified in Figure 2-3.

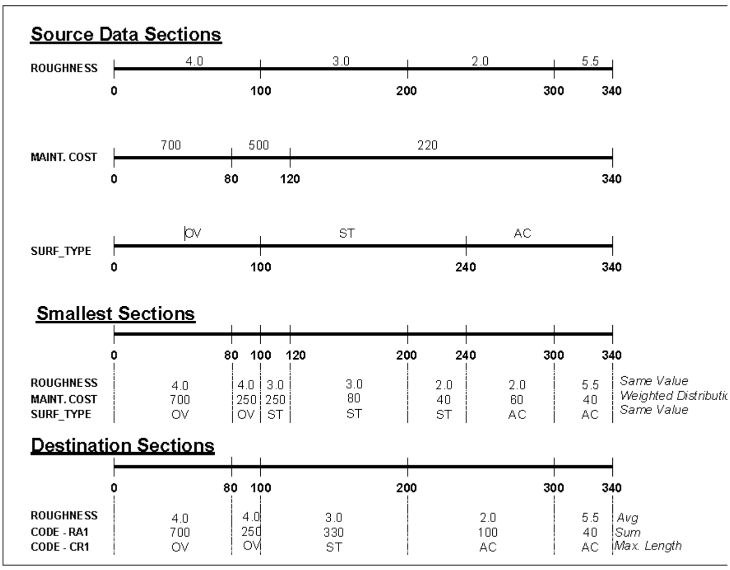

Figure 2-3: Dynseg Based on Road Condition
Source: HTC (2002)

The process includes;

1. Source data sections - automatic sectioning of the sections to the smallest denominator sections based on attribute section information,
2. Smallest sections - Transformation of the data from the source data sections to the smallest sections, based on a combination of a set of attributes and,
3. Destination sections - Transformation of data to the destination segments.

This transformation of data between sections requires certain rules. The data from the original source data sections is transformed into a number of small sections. This involves a combination or overlay of the 3 attribute data elements and creating small sections at each point where data changes for any of the attributes. The possible mathematical rule for the above example could be same value or weighted distribution based on length. The final stage transforms data from the small sections to final meaningful destination sections. The possible mathematical calculation rule for the process in the above example could be average, count, first, last, maximum, minimum, most length, standard deviation, sum, weighted average, etc. This is an endless list which varies depending on the data types (HTC, 2002).

Hans et al. (1997) use a verbal explanation to illustrate dynseg. One attribute table in the database may contain traffic data, another may contain pavement condition data, and yet another may contain roads inventory data. Dynseg, when performed using the appropriate attribute tables, new sections (read segments) can be generated. This can be done either interactively, or by updating existing segments using queries. Interactively, this is accomplished by selecting segments with the same pavement condition data and allocating similar visual symbols. Also, new segments may for instance be generated based on attribute queries from two datasets, one, where the IRI<3 and two, where the traffic volume aka **Average Annual Daily Traffic (AADT**> 10,000). Likewise, the roads inventory data may be updated with pavement condition data contained in another attribute table through dynseg. However, these attribute tables need not possess common linear extents. Further reference to dynseg application is made to Huang et al (2008).

In terms of GIS software, dynseg is a method of portioning arcs in the GIS database to reflect their underlying attributes thus making it possible to display data from numerous different tables on a single line without duplicating the route geometry. It is a way of referencing linear attribute data on demand, based on a variable segmentation of a single network. Dynseg is the process of computing the map locations of events stored and managed in an event table using a linear referencing measurement system and displaying them on a map (ArcGIS desktop help). Since GIS often takes the distance from the starting point of each road/route as an event measure, for road management systems that employ the dynseg concept, the LRM used should be based on that principle. This translates into a road network that is easy to understand and implement.

Demirel, (2002, p.74) asserts that "Dynseg solutions offered by GIS vendors are dependent on software platforms. In order to use one of these solutions, the core modules of the appropriate GIS vendor's software need to be deployed at the agency. Additionally, GIS vendors have prerequisites with respect to the conceptual data model design, which can limit the data modelling scope. For this reason existing databases need to be modified to take into account the prerequisites of the software data model."

2.7 Geographical Information Systems for Transportation (GIS-T)

GIS-T is an acronym for Geographical Information Systems for Transportation. These are interconnected systems of hardware, software, data, people, organisations and institutional arrangements for collecting, storing, analysing and disseminating transportation information about areas of the earth (Fletcher, 2000). GIS-T integrates particular types of information relating to transportation activities. It refers to the principles and applications of applying GITs to transportation problems (Miller and Shaw, 2001). GIS-T is a broad expression that encompasses all applications of GIS that are related to the management, planning and science of transportation features. There are diverse applications and users of GIS-T. The users have different objectives for employing GIS to transportation. Each objective portrays a variety of constraints based on the functions for which they require GIS-T applications. The most fundamental functions of GIS-T are those addressing issues relating to transportation networks and features associated with these networks. The features may be events or attributes of the transportation network. Today and in the past, government agencies, research institutions and even individuals have built GIS-T applications. It has in fact been receiving increased attention for a number of years now (Huang, 2002). GIS-T applications are not limited to roads but to all modes of transportation including air, water and rail. GIS-T also incorporate other transportation related objects such as pavement conditions, black spots, potholes and road signs in GIS databases. Their applications take a variety of dimensions e.g., traffic accident monitoring, management of bus stops, routing and scheduling of public transport, tracking of ships and trucks for delivery, designing new and improved routing algorithms, traffic analysis and control, environmental impact assessments, hazards mitigation, configuring and managing complex logistics systems and transport network designs for the future. The breadth of the field of GIS-T provides ample opportunities for the development of new innovative applications, and at the same time presents challenges to those who will try to integrate such diverse activities (ESRI, 2001). The need to model linear objects that represent transportation infrastructure and features associated with such infrastructure is what sets GIS-T applications apart from the general GIS applications (Guo and Kurt, 2004). In fact GIS-T is theorized as a product of a cross-fertilisation of an enhanced GIS and an enhanced **Transport Information System (TIS)** (Thill, 2000). A fully developed GIS-T has to meet many diverse needs including transportation, inventory, modelling and operational problems (Sutton, 1997). A data model, as an output from this Thesis, results from the most effective data structure for road maintenance data and is a GIS-T object-relational data model. This model seeks to identify a number of road maintenance objects, and organizes them logically in such a way that they can be used for road maintenance purposes. Figure 2-4 shows the connection between GIS, TIS and GIS-T.

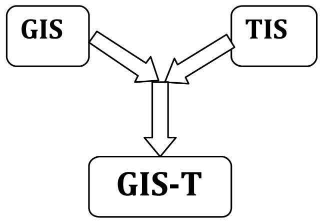

Figure 2-4: GIS-T, Product of an Enhanced GIS and Enhanced TIS
Source: Vonderohe et al. (1993) as cited by Thill (2000)

2.8 Geographical Information Technologies (GITs)

GITs also known as Geospatial Technology are a specialized set of information technologies that handle georeferenced data. Geospatial technologies support a wide variety of uses, from data acquisition (e.g., aerial imaging, RS, land surveying, and global navigation satellite systems), to data storage and manipulation (e.g., GIS, image processing, and database management software), to data analysis (e.g., software for statistical analysis and modelling) to display and output (e.g., geovisualization software and imaging devices) (DiBiase et al., 2007). GITs are a component of a broad domain that is referred to as Geographic Information Science and Technology (GI S&T). The other sub domains are Geographic Information Science (GIScience) which is a multidisciplinary research enterprise that address the nature of GI and the application of geospatial technologies to basic scientific questions (Goodchild, 1992) as cited by (DiBiase et al., 2007). The third domain is the Applications of GI S&T which includes the increasingly diverse uses of geospatial technology in government, industry and academia. These three domains are represented in Figure 2-5. The two-way relations that are half-dashed represent asymmetrical contributions between allied fields (DiBiase et al., 2007).

Success in road maintenance management depends on the convergence of processes, people and technology (McPherson and Bennett, 2005). Technology in this case refers to the science behind the methods used in road maintenance. “GITs are a set of specialized ICT tools 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, p. 3). Due to their capability to facilitate display and visualize spatial data, they provide an important feature for communicating, disseminating and sharing knowledge.

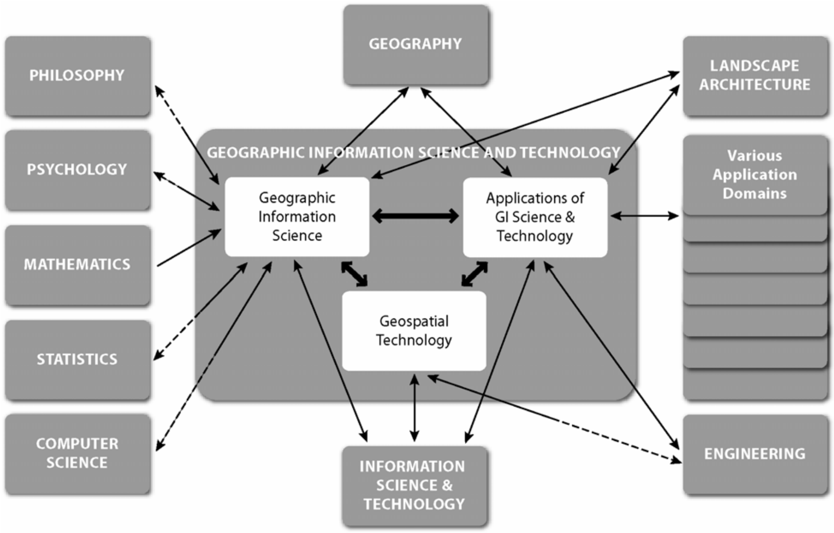

Figure 2-5: The Three Sub-Domains Comprising the GI S&T Domain in Relation to Allied Fields
Source: DiBiase et al. (2007)

GITs include four basic spatial tools, namely, GIS, GPS, RS and web based tools such as Google Earth which provides new ways of sharing information and visualizing near real time data. Figure 2-6 shows a graphical example of some 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.

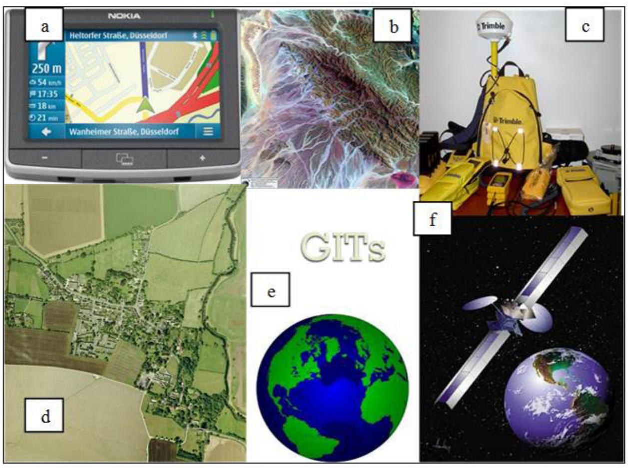

Figure 2-6: Examples of GITs

GIS are powerful computer-based tools for integrating and analysing spatial data from multiple sources. A GIS is a geographic database management system (Miller and Shaw, 2001). GIS permits geographically referenced information to be stored, edited, manipulated, and analysed to generate interpretive maps and related statistics relevant for decision making. It "is an intelligent technology which integrates attribute data and spatial features and manages the relationship between them" (Sutton, 1997, p.25). The storage, management and analysis of geographically referenced data is accomplished through integrating common database operations with unique means of visualization of geographic data and the analysis potential of maps (Ehrensperger et al., 2007). GIS assists users in spatial analysis and provides a base for interpreting how physical, social and economic factors interact in space (ibid). It distinguishes itself from RS and GPS technologies by enabling data from diverse sources to be integrated, analysed and even modelled, because of its powerful analytical functionality (GAO, 2003). "GIS is widely used in many activities, but its application in transportation has not been that common. The extension of GIS into transportation (GIS-T) offers the potential to integrate transportation data into GIS. The integration of transportation data in GIS faces a number of barriers though, which can be broadly categorized into data attribution and network representation issues. If GIS is to succeed as a transportation technology, it must be capable of integrating different levels of network representation and data attribution and have the ability to link with other transportation technologies" (Sutton, 1997, p. 25). "GIS data models originated in the need to represent the contents of static maps, but have gradually been extended to handle the special needs of spatial analysis and modelling. These include many of the kinds of analysis and modelling needed in transportation" (Goodchild, 1998).

GPSs are accurate worldwide navigational and surveying facilities based on the reception of signals from a number of orbiting satellites which were placed into the orbit by the U.S. Department of Defence since the 1970s (Mintsis et al., 2004). They are managed by the United States government and are freely available for persons with GPS receivers anywhere on the earth. These satellites traverse the earth twice a day in a precise orbit while transmitting signal information to the GPS receivers. The receivers use triangulation of time differences between signals from four or more GPS satellites to calculate the latitude and longitude of a receiver on earth. GPS provide reliable location and time information in all weather and at all times. This information is available for GPS receivers on or anywhere near the earth provided there is no unobstructed line of sight. In the context of this Research, 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 (Ehrensperger et al., 2007). These other landmarks may later be used to reference satellite images or other spatial data layers.

RS is the acquisition of information about an object or phenomenon, without making physical contact with the object. It 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 (Ehrensperger et al., 2007). It has two facets which are intimately linked to each other; the technology of acquiring data through a device which is located at a distance from the object, and analysis of the data for interpreting the physical attributes of the object (Gupta, 2003). RS provides images of the earth's surface that can be used to identify especially different types of land cover. The result from RS is a classification of objects on earth – i.e., both on the surface, in the atmosphere and to a few meters under the sea.

Mapping and cartography terms are often used synonymously if not together. They are a traditional approach of GITs, which use maps and sketches of features in the geographic space to carry out spatial analysis. They are a discipline and science with a long historical background, which dates back probably as long as the history of the written word (Ehrensperger et al., 2006). Cartography is the study and practice of making maps. It combines science, aesthetics, and technique and builds on the assumption that reality can be modelled in ways that communicate spatial information effectively. Modern cartography is closely integrated with geographic information science (GIScience) and constitutes many theoretical and practical foundations of GIS. The term Mapping is also sometimes used instead of surveying when dealing with geospatial data collection. The mapping referred to in this context is map production which involves determining the scale/level of detail and content of map database, entry criteria and symbol specification for geospatial data.

There are numerous advantages associated with the use of GITs. These include improved mapping, greater efficiency in retrieval of information, faster and more extensive access to the types of GI important to planning, improved analysis, better communication to the public and fast access to information for various application processes. Ehrensperger et al. (2007) observe some key issues to consider in association with the implementation of these technologies. These issues include relevance of content which often necessitates the identification of the various stakeholders to help in defining of content within the GIS, appropriate technology, a crucial aspect of successful GIT implementation and accessibility, which in particular includes costs of hardware, software and data.

2.8.1 GIS Software

GIS software is that software that allows for geographic datasets to be collected, managed, analysed and displayed in the same environment. Typical tasks that can be performed with ordinary GIS software include:

1. Viewing or exploring, creating, editing, and storing spatial data,
2. Conflating datasets - this involves integrating datasets from different sources,
3. Transforming - into different coordinate systems, different representations, re-sampling, resulting in new representation or formats of the same data,
4. Querying - this results into selections from the dataset,
5. Analysing - this results into new datasets,
6. Creating of maps - this is usually the last stage in manipulating geographic datasets. It allows for visualisation of data.

GIS software come in two categories - open source and proprietary software. Open-source software (OSS) is computer software that is available in source code form. The source code and certain other rights normally reserved for copyright holders are provided under a software license that permits users to study, change, improve and sometimes also to distribute the software. Open source software is licensed under GNU General Public License. Proprietary software on the other hand is computer software licensed under exclusive legal rights of the copyright owner. The purchaser, or licensee, on payment of a considerable amount of money, is given the right to use the software under certain conditions, while restricted from such uses as modification and further redistribution.

GIS software packages are distinguished into several types:

- **Desktop GIS** - this is the most used type of software, basically used to create, edit, manage, analyse and display geographic data, and is often categorised into GIS Editor, GIS Analyst or GIS Viewer.
- **Server GIS** - offers the same functionality as desktop GIS but additionally allow these operations via networks, also known as geoprocessing,
- **Mobile GIS** - are used for data collection in the field. Examples include ArcPAD, Fieldworker, Location Based Service (LBS), Fugawi, HGIS, MapXtend, Palm OS GIS Software, and PocketGIS,
- **WebMap Servers** - these are used to distribute maps over the internet,
- **WebGIS Clients** - used for data display and to access analysis and query functionality from server GIS over the internet or intranet.

WebGIS clients are differentiated into thin and thick clients with the former having provision for display and query of geographic datasets while the latter provides additional tools for editing, analysis and display.

The type and operating system of the GIS software packages mentioned in this Thesis are presented in Table 2-5.

Table 2-5: Examples of the GIS Software Featuring in this Thesis

Software Name	Type	Operating System
ArcView 3.x, ArcGIS, ArcSDE, ArcIMS, ArcWeb services and ArcGIS Server.	Proprietary desktop and web map server GIS software (ESRI[3] – Products)	Windows, Linux, Unix, web
Intergraph	Proprietary GIS software.	Windows, Unix, web
ERDAS Imagine	Proprietary desktop now owned or together with Intergraph	Windows, web
IDRISI	Proprietary	Windows
ILWIS (Integrated Land and Water Information Systems)	Open source desktop	Windows
TransCAD	Proprietary GIS software	Windows, web

3 ESRI, an acronym for Environmental Systems Research Institute is a software development and services company providing Geographical Information Systems (GIS) software and geodatabase management applications.

Most of the modern GIS have got the dynamic sectioning functionality. For applications requiring dynseg, the database management system that is chosen should be compatible with one of these GIS systems. Some of the GIS systems known to have dynamic sectioning functionalities are: ESRI's dynseg module, TransCAD's dynseg and Intergraph's Segment Manager.

TransCAD, a proprietary GIS software, boosts of being the first and only GIS designed specifically for use by transportation professionals' to-date. Its intention is to perform basic storage, display, management and analysis of all modes of transportation data. It combines GIS and transportation modelling capabilities in a single integrated platform thus providing capabilities that do not match any other package. It provides a powerful GIS engine with special extensions for transportation, mapping, visualization, and analysis tools designed for transportation applications and application modules for routing, travel demand forecasting, public transit, logistics, site location, and territory management. It has applications for all types of transportation data and is ideal for building transportation information and **Decision Support Systems (DSS)**. TransCAD can display and analyse linearly referenced datasets without conversion, a technique that uses dynseg for transportation analyses. The same dynseg functions are used to merge and analyse multiple linear-referenced datasets. Further details on this software can be obtained from their website. (See TransCAD, 2011)

Intergraph, also proprietary, is a provider of engineering and geospatial software with which customers can visualize and organise complex vast amounts of data thus making processes and infrastructures maintained and safe. It operates through 2 divisions, 1, the Security, Government & Infrastructure (SG&I) where transportation lies. In this division, Intergraph provides geospatially powered solutions. The second division, 2, is the Process Power and Marine (PP&M), where enterprise engineering software for the design, construction, and operation of plants, ships, and offshore facilities is provided. The Multilevel Linear Referencing System (MLRS) application and segment manager of Intergraph provide the basis to build, maintain, and analyse a multilevel, temporal linear referencing system for representing road networks. Further reference on the Intergraph software and its products are available at Intergraph (2011). Intergraph is equipped with a SDI application which allows for the ability to collaborate and distribute data amongst departments.

2.9 Spatial Data Infrastructures (SDIs)

In much of the literature on spatial data, SDI is a concept that is often used synonymously with GIS. There are many definitions of an SDI. Using Chan et al. (2001)'s definitions from various sources, the definition by the Dutch National Geographical Information Infrastructure (NGII) best suits the context of this Research. The NGII defines SDI as a collection of policy, datasets, standards, technology (hardware, software and electronic communications) and knowledge providing a user with the GI needed to carry out a task. This evolution of SDI from basic individualistic GIS has facilitated efficient and easy accessibility to geospatial datasets, and thereby removed barriers to utilisation of GIS that are spread across several institutions (Musinguzi, 2007).The shift from GIS to SDI resides in the perception that the bulk of the cost of setting up a GIS in an organisation lies in the purchase of hardware, software, hiring of personnel and installation of office infrastructure (ibid). Experience, has however shown that data capture and management actually take the largest portion of this expenditure (Rhind, 2003).

Spatial data is very costly to capture. In addition to the initial cost of data capture, more resources are required to effect the frequent updating needed to facilitate accurate decision making based on most current information. The major difficulties encountered by implementers of GIS in organisations originate from three operational requirements (Rajabifard and Williamson, 2001a; b):

1. Enterprise GIS databases require data that do not fall under the exclusive jurisdiction or operation area of a particular institution,
2. Organisations require more data than they can afford to capture using their own resources,
3. Incompatibility of data collected by different organisations

Organisations have in effect moved to form partnerships that are aimed at sharing their spatial data. This strategy requires a framework to ensure smooth data sharing attempts.

Interoperability is a key requirement for data sharing. It is the ability of systems to effectively provide, accept and use common services. It is enforced through adoption of consistent standards for spatial data technical specifications, such as data formats, database schemas, object concepts and application syntax (Musinguzi, 2007). The increasing need and desire for spatial data sharing has made issues of data interoperability prevalent in many application areas road maintenance inclusive.

For effective sharing and integration of spatial data, it is a requirement that the data is collected and spatially referenced in a consistent manner (Groot and McLaughlin, 2000). To accomplish this efficiently, a set-up and conformation of common standards for capture, structure and documentation of spatial datasets is a prerequisite. Within the framework of agreed institutional arrangements, potential users can then discover, explore and manipulate datasets with facilitation. SDI's constitute that framework within which data is captured, documented and availed to the wider community thus widening the scope of GIS from organisational levels.

Although manifested in different formats for different countries, SDIs exhibit certain generic features that cut across all definitions. The components of an SDI include:

1. People/Institutions and constituting partnerships,
2. Networks, providing the means to access data,
3. Policies that guide access to data,
4. Technical standards prescribing structured approaches to development and access of data, and
5. Spatial datasets developed by institutions under their respective individual mandates but in conformity to agreed standards.

These components are shown graphically in Figure 2-7.

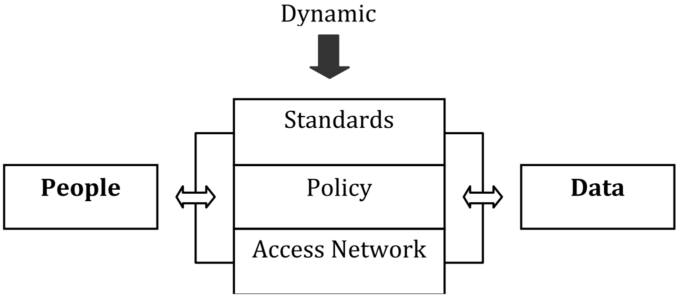

Figure 2-7: Nature and Relationships between SDI Components
Source: Rajabifard and Williamson (2001a)

The concept of SDI is part of the backbone on which gaps and limitations in using GITs for road maintenance has been discussed. It is based on the principle that organisational standalone GIT implementation is costly and time consuming. The basis of SDIs is to facilitate the sharing of GI that has been a concern since the early days of GIS conception, mainly due to the cost of collecting and maintaining the information. Data sharing once depended on the establishment of data transfer standards eventually evolving into the creation of clearing houses and web resources that centralise links to various GI sources all of which were principally data oriented. However, there was a growing dissatisfaction among clearing house users as to their functional capabilities. The conception of SDIs has changed the data oriented view to a service (user) and application-oriented view which advocate for the creation of shared, distributed and interoperable environments through web services (Clodoveu and Leonardo, 2005 and Clodoveu and Fonseca, 2006).

2.10 Causality and the Principle of Causality

Causality is the relationship between an initial event (the cause) and a following (2^{nd}) event (the effect), where the second event is understood as a consequence of the first. In common usage, causality is also the relationship between a set of factors (causes) and a phenomenon (the effect). This term is used in all physical, natural and social sciences. As such, causality is a basic assumption of science. Within the scientific method of research, scientists set up experiments to determine causality in the physical world. Imbedded within the scientific method and experiments is a hypothesis or several hypotheses about causal relationships. Still, the scientific method is used to test these hypotheses.

The principle of causality is one of the primary propositions known to people in their ordinary lives. This principle states that for everything there is a cause. According to the Theological and Philosophical dictionary on the web (Causality, 2010), the causality principle states that all occurrences are the necessary consequences of previous events.

In the sciences, particularly the natural sciences, one distinguishes general from specific causes, the main from the secondary, the internal from the external, the material from the spiritual, and the immediate from the mediate, with varying numbers of intervening stages.

Besides the concept of SDI, the principle of causality is another factor on which the gaps and limitations in GIT for road maintenance have been identified. The gaps are the effects caused by the limitations. For additional knowledge on causation and related terminology, reference is made to Bunge, (1982; 2009).

2.11 'Mode 2' Knowledge Production

The term 'mode 2' is a concept that is used to describe the contemporary way of producing and co-producing scientific knowledge. This form of knowledge production is driven by context, focuses on the problem and is transdiciplinary as argued by Gibbons et al. (2004) and Limonges, et al. (1994) as cited by (Lating, 2009). Transdisciplinarity is a new form of learning and problem solving involving co-operation among different parts of the society and academia in order to meet complex challenges of society (ibid).In this type of research, researchers work jointly to develop shared conceptual frameworks and methodological approaches that integrate and transcend their respective disciplinary perspectives to address a common problem. In the context of this Research, the researcher, an academician from the university worked with road engineers and GIS experts in road maintenance organisations in aligning the conceptual and methodological frameworks in order to devise strategies of enhancing GITs in the road maintenance sector. In this way, the Research proceeded across, between and beyond disciplines. For further conception of transdisciplinarity, reference is made to (Gibbons et al., 1994 and Nowotny et al., 2001).

'Mode 2' knowledge production contrasts with the traditional 'mode 1' wherein knowledge is produced strictly within a given discipline thus disciplinary. When knowledge is produced by academically qualified professionals in universities based on investigator initiated constructs, this is referred to as 'mode 1'. 'Mode 2' knowledge production is more heterogeneous and organisationally varied. It is under "mode 2" that knowledge production is realized to root from diverse groups, to be widely distributed across sectors and in society. In 'Mode 2' knowledge is produced in the context of its application, and in an inclusive manner taking into account interests and values of the society at hand (Nowotny et al, 2003; 2011). The 'mode 2"s dispersed and transient way of knowledge production leads to results which are highly conceptualized (Gibbons et al., 2004; 2010). This can be explained in the sense that solutions needed for the final problem are typically beyond the boundaries of any single discipline. This Research embraced the 'mode 2' knowledge production line as it was done in the social context of the problem and in fact, the methodological framework presented in Chapter Six is not within the confines of a single discipline.

2.11.1 Triple Helix

One way of implementing 'mode 2' knowledge production is by adopting triple helix arrangements. Triple helix is defined as a collaborative relationship between the university, industry and government. Triple helix stresses the need for cooperation between these three participant categories. However, Leydesdorff and Etzkowitz (2001) affirm that such collaboration may happen only when the functions of university, industry and government transform in such a way that enables each institutional sphere at specific and relevant situations to assume the role of the other. The purpose of the triple helix is to stimulate knowledge-based economic development by drawing resources from all the three members of the helix. It is evident that the communications, negotiations and collaboration that take place between institutional partners in the triple helix alliance is a strong foundation for implementation of mode 2 type of knowledge production (Leydesdorff and Meyer, 2003 and Etzkowitz and Leydesdorff, 2000).

This Triple Helix syndrome is evolving in Uganda, and transformations are taking heed within the individual institutional spheres of the university, industry and government. Lating (2009) cites the passing of an institutional research and innovation policy in Makerere University in 2008 which saw the transformation of the School of Graduate Studies (SGS) into a Directorate of Research and Graduate Training (DRGT) an indicator of initiatives for collaboration between the directorate, industry and government. Likewise, the phase III Sida funding support to Makerere University saw a couple of doctoral students from the industry benefit from the sponsorship. This has seen participants from the innovation and cluster subprogram of the College of Engineering Design and Technology (CEDAT) spearhead the triple helix phenomenon within their research, to greater heights.

CHAPTER THREE
A REVIEW OF GEOGRAPHICAL INFORMATION TECHNOLOGIES FOR ROAD AND RELATED APPLICATIONS

3.1 Introduction

This Chapter is intended to contextualise the Research and for the reader to appreciate the multitude of GIT applications for road management. It gives an overview of both research and on job projects of GITs for road applications. It also identifies with research on the use of GITs in disciplines other than roads. In some of these disciplines, data on roads is a prerequisite for the application. Some methodological concepts are also reviewed and presented in this Chapter. As familiarity with works from especially previous researchers unfolds, it is important to appreciate the background circumstances of the countries in which these researches have been accomplished. This is in comparison with Uganda's background, the Country in which this Research is undertaken. The context in which this Research is undertaken differs somewhat from what has been accomplished previously. This is because of the lag in adapting to GIT technological changes that is faced by the sector, among other reasons that are presented in the succeeding results oriented chapters.

3.2 GITs in Various Road Applications

The use of GITs 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 subject.

Since the 1990's, planners, policy makers, and transit managers began to comprehend the importance of especially GIS as a tool in their day to day work. GIS, GPS, RS 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 as is noted in the following literature. This is explained in relation to its integration capability to handle data collection, management and analysis, as the rest of the technologies are principally collecting data often for input into the GIS. As a matter of fact GIS applications are dependent on data that is accumulated through RS and GPS. RS 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 infrastructure facilities. RS techniques and spatial data analysis through GIS have been used in a number of disciplines as decision support tools. In the following discussion therefore, much of the applications of the said technologies are within the same projects. Transport applications such as forecasting travel demand, travel analysis based on activity, planning of transit routes and analysis of markets, monitoring vehicles and real-time operational control, customer information systems, Paratransit and emergency vehicle dispatching, congestion management, etc., have been pin pointed. Some other GIS-T applications include; transportation/land-use planning, design of traffic analysis zones, evaluation of safety benefits, transit service area analysis, data attribution and network representation in GIS-T, the integration of GIS concepts into transportation network data structure, linking urban models and GIS and impact assessment. The following sections present previous research in GITs for transportation applications. They have been grouped in context based frames.

3.2.1 Urban Transport Planning

Urban transportation planning is that branch of planning that involves the evaluation, assessment, design and location of transportation facilities including highways and public transport routes. The process has historically followed the rational planning model of defining goals and objectives, identifying problems, generating alternatives to address the problems, evaluating alternatives and developing suitable plans. Prastacos (1991) discussed the integration of GIS technology in urban transportation planning and modelling. He identified the problems faced then and the solution that GIS could provide. Prastacos analysed the designed considerations and data needs for implementing this GIS model-based urban transportation analysis system. Thong and Wong (1997) developed a prototype GIS for urban transportation planning in a district of a South-East Kowloon, Hong Kong to assess the performance of a proposed transportation system. Thong and Wong (1997)'s system required two major datasets (a) spatial information, including digital maps showing road networks, junctions, aerial photographs, etc. and (b) attribute information, including population and employment figures, land use activities, traffic counts, etc., with room for additional data deemed required for future urban transport prediction. It is these datasets that were manipulated under the 4 modal components of the Urban Transport Planning System (UTPS) to predict trip assignments for the road networks. The 4 modal components include trip generation, trip distribution, mode choice and route assignment. The GIS-T database of Thong and Wong (1997) was designed to be able to:

1. Perform realistic simulations of the transport network in both two-dimensional and three-dimensional forms,
2. Manipulate various types of transport related information in one consistent database, and
3. Support tools for scenario comparison between existing and future network flow change in a predefined study area.

As a result, both the existing and future network flow performance could interactively be displayed in graphical formats hence availing transport planners' better understanding and insight to assessing the performance of the proposed transportation system.

GIS was also used as a tool for planning new road stretches in respect of climatological factors by Gustavsson et al. (1998). Primitively, the planning of new road sketches was performed manually with evaluations using field studies. These studies involved the rating of the local climate to estimate for example winter road maintenance costs and the problems that would be expected along the road. In this new approach however, distinct weather types were mapped separately and in order to get an overview of surface temperature variations in the landscape and the frequency of occurrence, the climatological features were classified according to the extent of temperature decrease (or increase in some cases). They used three risk classes for low temperatures (2, 1 and 0), with lowest temperatures being assigned the value 2. One (1) was assigned as an intermediate class and the average of the whole area was assigned as 0. When a higher than average temperature was expected, for instance in many urban areas or sunny slopes, risk classes ÿ1 and ÿ2 were used. They obtained frequencies of the studied situations from weather statistics and multiplied them by the risk classes. Maps for each weather situation were then combined into one map showing the expected relative risks and frequencies of low temperatures as climatological risk points. These climatological points, of for instance two alternative road stretches, could then be compared in order to evaluate the differences in local climate, and hence provide a recommendation for new road stretches.

With the case study of Riyadh, the Kingdom of Saudi Arabia, Alterkawi (2001) discussed with examples the application of GIS in Transportation Planning. Alterekawi (2001) highlighted and discussed the fields in which GIS was fundamental together with some analyses and concepts from GIS that are relevant for transport management. His discussion fundamentally included the planning of travel demand, long and short range planning, analysis of deficiencies, analysis of air quality, and allocation of resources. The discussed concepts and analyses included dynseg and networking, buffer analysis, and shortest path analysis.

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, and identity tools in Arcinfo, and these tools proved useful. Shapearc is a tool that writes spatial and attribute information of shapefiles to ArcInfo coverages. 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. This Research, in a way, is another case Study to Uganda where on implementation of the developed component strategies and model, will affirm the findings that GITs can effectively be used in roads mapping for sustainable decision making.

Even though not urban planning, per se, a GIS and Multi Criteria Evaluation and Analysis (MCE) based model for forest planning was developed by Abdi et al. (2009). The requirement was to design a forest road network with the lowest construction cost amidst other technical demands. MCE based on six factors was used to evaluate the costs of six road alternatives that met the technical requirements. These factors were compared in a pair-wise comparison in the context of the Analytic Hierarchy Process (AHP) to develop weights of map layers. These weights and factors were then entered into the MCE module to create a final suitability map using GIS. Pegger, an ArcView GIS extension that helps foresters and forest engineers with initial road planning and designs, was used to design the six road network alternatives with regard to forest road standards. The results illustrated the capability of GIS to improve the planning process.

Overall, these urban planning initiatives in the various study areas are inclined to environments where GITs are well founded and the expertise to handle the analyses are readily available. As this is not the state of affairs in the current Study area, Uganda, research can at the moment be geared to devising strategies on how to get the transport planning authorities adapt to GIT functionalities for planning purposes.

3.2.2 Information Management Systems (IMS)

Information Management Systems (IMS) refer to those schemes of managing information that is used to analyse operational activities in organisations. They are either automated or defined as support to human decision making hence providing information needed to manage organisations efficiently and effectively. IMS involve three primary resources; people, technology and data or information. **Spatial Decision Support Systems (SDSS**) are examples of IMS. SDSS are DSS that make use of spatial data to support spatial decision making. As highlighted in the following scripts, GITs have been assuming the technology resource in a number of road IMS.

Lee et al. (1989) developed a prototype Road Information System (RIS), a special purpose GIS that collected, organised and disseminated information related to the street and highway networks in a city or region. The basic structure was composed of the road and street network which was constituted of a series of nodes and links by which the attributes from the different applications were referenced. The structure was designed to serve a number of applications such as road construction and maintenance, route determination and guidance, road inventory, planning, administration, and traffic management.

Rebolj (1998) integrated GIS functionality in an information system to support the important stages of the road life cycle encompassing road design, evaluation and construction. Together with a conventional relational database, he maintained a spatial database with GIS functionality. Besides the basic GIS functions, the spatial data management contained additional functions for executing more complex specific processes such as geographic determination of the basic road corridor, different road analyses, and visualization, (ibid). The aim of this Study was to define a framework within which GITs can be enhanced for RIM in Uganda and specifically structuring GIS-T data for road maintenance analyses. This data structure is intended to support maintenance activities that lie in the construction category of the road life cycle. In this sense, the Research is related to Rebolj (1998) by virtue of integrating GIS-T data for road maintenance.

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 induced 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 the Indian Remote Sensing (IRS) satellite's Panchromatic (PAN) data of 5.8 meter resolution and Linear Self-Scanning Sensor (LISS III) data. The production of maps was suitable due the PAN sharpened data.

This research clearly raised 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. This again relates to the motivation of the Research in this Thesis. 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 made of 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)**. The most recent data that includes ETM+ images has however been affected by an error caused by Scan Line Corrector (SLC) sensor failure. This Research has ascertained 2 reasons for the limited utilization of satellite imagery as one of the components of GITs. First, despite the fact that this imagery is downloadable from various geoportals, there is an obvious limitation of internet bandwidth to accommodate a number of these downloads. Second, interview findings have registered a deficiency in the available expertise to analyse satellite imagery. The Research however has developed a methodological framework that can be used to enhance the use of GITs in RIM. Otherwise, Karandikar et al. (2003)'s research demonstrated that with readily available data, GITs (GIS in this case) are reliable decision support tools. Their use for RIM cannot be an underestimated.

As presented by Karakaidou (2004) at the FIG[4] Working week, GIS was used as a tool in the Routine Maintenance Management System (RMMS) of Egnatia Odos Motorway. The initiative resulted from the need to outsource relevant works of the routine motorway maintenance through shifting from the traditional procurement of direct labour to using a maintenance management system. The designed IMS has managed to control the quality and effectiveness of the maintenance services of contractors. "The RMMS database comprises information relating to the geographical location of the road network, maintenance requirements, required resources for planning maintenance works and the performance of the maintenance contractors" (Karakaidou, 2004, p. 1). In the long run, through use of the system, maintenance costs expenditure by the contractors is managed and controlled. Karakaidou (2004)'s research clearly expounds on the literature exposing the advantages of GIT use as prior mentioned in Chapter Two. It minimises maintenance costs, in this case by better management of contactors and the available resources. The planned OPRC by UNRA in Uganda, where the contractor decides what do, where to do it and how to do it, has a lot to learn from Karakaidou (2004)'s work. The requirement of an IMS to spearhead monitoring of the contractor during the contract period is paramount. However, this can only be possible with the right data structure, which is one of the outputs from this Study.

Rao et al. (2006) developed a GIS based Maintenance Management System (GMMS) for major roads of Delhi. This was in a bid to evaluate the existing condition of the roads and to suggest measures needed for their improvement. The utmost intension was so that cost-effective modern technologies could be used to provide higher level serviceability by applying regular and timely maintenance, (Rao et al., 2006). This development was made in order 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 was aimed at developing a framework within which GIT benefits could be realised and in turn benefit the road maintenance sector of Uganda. The developed GIS-T data structure for road maintenance is envisaged to specifically allow more meaningful analysis of road condition for better presentation to road maintenance decision makers.

Zulkifli et al. (2010), also advocate for the use of GIS in road maintenance applications. They argue that, prior to preventive maintenance works, a good database gathered through GIS is a useful tool in database management for road maintenance engineering. Zulkifli et al. (2010) adopted the ArcView GIS application software to explore the effectiveness in managing a database for roads. Their spatial datasets mainly focussed on roads (federal and state roads) and other road assets such as bridges, culverts, kilometre posts and signage. Table 3-1 shows an attribute table of the spatial datasets used in their exploration. Their research concludes that GIS has advantages of fast data recall capabilities, relative ease of use, minimizing duplication of efforts in data collec-

[4] FIG stands for the International Federation of Surveyors. It is an international, non-government organisation whose purpose is to support international collaboration for the progress of surveying in all fields and applications

tion, improving data currency, accuracy & consistency, promoting data sharing culture & enhancing team spirit and secure & better organised map data. These are just about the outcomes anticipated to accrue from adoption of the methodological framework and data model as outputs from this Research.

Table 3-1: Attribute Table

Database	Road	Km Posts	Signage	Bridges/ Culverts
	Seg_id Route_No Road_Name Lane_Length Lane_Width No_Lane Rd_Class Pav_Type Status District State Image	Seg_id Route_No Section_No Primary_Dest Distance Sec_ Destination Distance Status District State Image	Seg_id Route No Type Date _Instll Sign_Code Sign_Desc Status District State Image	Seg_id Struc_No Struc_Type Location Route_No Yr_Built Length Width Status District State Image

Source: Zulkifli et al. (2010)

A highway management system based on WebGIS was designed and implemented by Xie (2010). This was basically as an effective management tool to pace the rapid growth of the highway with timely pavement maintenance decision support. WebGIS is a product of the web and GIS technology that is based on the technical standards and communication protocol of the internet. It relies on the internet or intranet to provide users with information storage that is distributed in space, through data sharing, exchange and collaboration. The advantages of WebGIS include the reduction in costs and implementation complexities of the server, replacement of the physical desktop GIS and a provision for personalised service over network resources. Xie (2010)'s system uses dynseg to link geographical and attribute information of the road. Even though robust, this kind of system may not be easily employed in the situation of Uganda due to the slow development of internet services in some parts of the Country. However, the concept of dynseg is integrated into the road maintenance data model developed through this Research.

To assist in the evaluation of several road alignment alternatives, a computerized highway design model based on GIS was proposed by Syamsunur et al. (2011). The model was intended to ensure that basic road functions and traffic services between places are maintained. The motivation is based on the fact that an economic and safe route involves the analysis of several alternatives and can therefore not be determined manually. This is because the road design involves complex processes based on detailed assessment of existing geographic features, geology and terrain, potential land use and environmental evaluation, which were all effectively managed by GIS. An expert system based on KAPPA-PC software was used together with GIS. The KAPPA-PC package is composed of programs for geometric highway design that is written in KAL (Kappa pc Application Language). The variables of highway geometric design in consideration included the characteristics of traffic flow, vehicle size, sight distance, super elevation and topography. The idea of this model grounds the assertion by Rebolj (1998) that GIS functionality is fundamental in supporting various stages in the road life cycle.

Data are at the forefront of all the designed systems as discussed in this section. With knowledge and existence of the right data and their structure into the GIS, maintenance management systems can always be designed and used by the deserving agencies. The various stakeholders in the road maintenance sector of Uganda have varied knowledge on the required data to be included in their GIS. Where GIS exists for an organisation, there is no standard schema for the datasets in their custody. One of the principal outputs from this Research is a GIS-T data model for organisations within the road maintenance sector so that application specific analyses can be accomplished on standardized datasets.

3.2.3 GIS-T Data Models

GIS-T data models are those GIS data models abstracting transport related data for various transport applications. Dueker and Butler, (1999a; b; 2000) developed a GIS framework and principles for sharing transportation data. Their intention was to provide guidance and clarify on roles of participants, producers and integrators of transport related data. Dueker and Butler (1999a; b; 2000)'s fundamental principle was the need for a common data model that holds transportation features (not their graphical representations) as the objects of interest. A brief description of their model is shown in Figure 3-1.

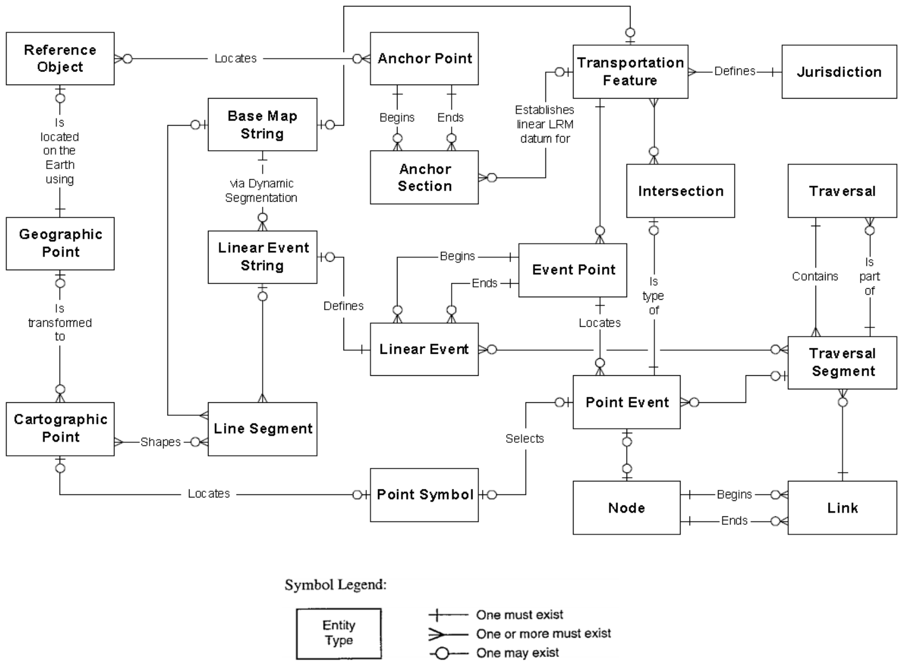

Figure 3-1: A Brief Description of Dueker and Butler's GIS-T Data Model
Source: (Dueker and Butler, 1998)

This model idea is in relation to objective 3 of this Research and in line with research questions (iv) and (v) dealing with effective representation of road maintenance data in a GIS. Dueker and Butler (1999a; b; 2000) identify with 2 central principles:

1. The separation of graphics, topology, position, and characteristics and,
2. The establishment of a schema for transportation features and their identifiers.

The framework and principles by Dueker and Butler (1999a; b; 2000) is an elaboration of their GIS-T data model with suggested implementation choices as documented in Dueker and Butler (1998).

Dodge and Alesheikh (2005) presented an object-related geo data model from which a transportation geodatabase for Iranian roads would be created. Their model provides a context within which a GIS can quickly and easily accept the input from a wide range of users to accomplish their transportation management goals. The model's intention was an initial structuring of transport data and was specified in the **Unified Modelling Language (UML)**. Dodge & Alesheikh's (2005)'s model is an enterprise data model from which application specific data models can be developed. This Research however presents an application specific data model for road maintenance. It emphasizes linear referencing and dynseg principles which are quite fundamental in decision making for linear features under which road maintenance applications are constituted. The advantages of dynseg as highlighted in Chapter Two are to be realised on adoption and implementation of the model developed by this Research. Unfortunately, attempts to receive and present more information on Dodge & Alesheikh's (2005) data model for appreciation in this research were futile.

A methodology for the development of a GIS network data model for the city of Plovdiv, Bulgaria was proposed by Filipov and Davidkov (2006). The model presents all the components and requirements related to routing and analysis of multimodal transport systems, such as various modes of transportation, restrictions on the network and the complex turns (ibid). Filipov and Davidkov's model is proclaimed as an obligatory base for development of complex process models. Process models are frameworks with several organised transportation elements that are concerned with how activities are conducted. The elements of Filipov and Davidkov (2006)'s model are composed of 2 main themes, those that are spatially related to the transportation network as in Figure 3-2 (a), and those additional factors that are logically related to the transportation network as in Figure 3-2 (b).

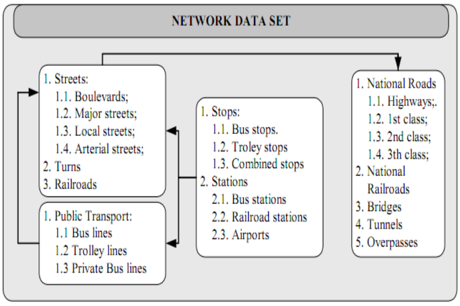

Figure 3-2(a): Network Data Model Set Elements

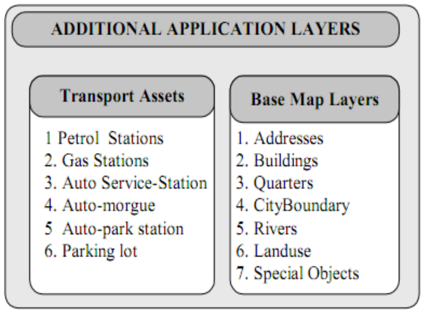

Figure 3-2(b): Additional Elements of the Network Data Model

Source: Filipov and Davidkov (2006)

Analysis and application capabilities of the developed model include but are not limited to shortest path finding, closest facility locations, origin-destination costs, vehicle routing and posts deliveries. The difference between Filipov and Davidkov (2006)'s model and the model from this Research is that the former is a process data model for transportation and the latter is an object data model for road maintenance. In the object data model, several transportation objects are identified and organised so as to aid decision making. Some constructs for the object data model discussed in Chapter Seven, e.g. the relevance of logical objects on the transportation network, accrued from Filipov and Davidkov (2006).

A multi-dimensional conceptual data model for transport applications was introduced by Demirel (2004). Demirel's model was in reference to the emerging data management needs of road administrators which require data integration from their various isolated systems. Demirel (2004) argues that since road objects can be static or dynamic, referenced to one, two, three or four dimensions; the traditional 2-D planar road data models are insufficient to support data integration. His presented model involves multi-dimensional location referencing, 3-D geometry and time. In 2002, Demirel attested his PhD on 'An integrated approach to the conceptual data modelling of an entire highway agency' (Demirel, 2002). Even though the gist of Demirel (2002)'s research was on data modelling for applications of the entire highway agency, the research findings and approaches to data structuring feature in the data model proposed for road maintenance decision support in this Thesis. As is emphasized in Chapter Seven, the practice of multi-dimensional location referencing is a future reservation for road maintenance applications in Uganda. This is because of the current stage in evolution of GIS data for decision making in the sector. Currently, the chainage (distance in km from the beginning point location of the road) should be adequate as the only linear reference to point and linear events subject to road maintenance.

3.2.4 Dynamic Segmentation (Dynseg)

At the University of Toledo and in cooperation with the City of Toledo, in North-Western Ohio, United States, Chou et al. (2002) implemented the dynseg capability of GIS in a Pavement Management Information System (PMIS). Chou et al. (2002) argue that the dynseg method produced better pavement management decisions since the actual street conditions were better represented. In their presentation, Chou et al. (2002) show how pavement images were linked to; the dynamically segmented sections of the road, resurfacing priority, ride quality rating and traffic volume on airport highways. Figure 3-3 shows a map display of the images on the dynamically segmented sections. Dynseg in Chou et al. (2002)'s research was a necessary tool for the PMIS as it allowed multiple attributes associated with the condition of pavement segments to be stored and displayed efficiently. Additionally, the cooperation with the city of Toledo highlights success envisaged from helix partnerships between government and academia.

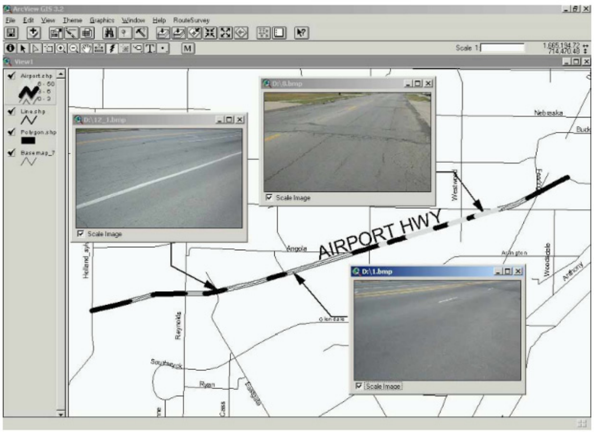

Figure 3-3: Pavement Images Linked to Sections
Source: Chou et al. (2002)

Still in line with dynseg, Jelokhani-Niaraki et al. (2009) designed a road maintenance data model using the dynseg technique. The logical data model shown in Figure 3-4 was 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 of which this Research is in sync. Despite its limitations, the traditional arc-node data model was being used in their jurisdiction. In the arc-node model, roads are represented as linear features between two nodes each with associated attributes. The attributes are integrated such that they are restricted to arcs with similar length and location. These models do not efficiently present concentrated and precise road segments. Additionally, the arc-node data structure handles the linear feature as an arc using a Cartesian coordinate system. With this structure, it is not possible to present road data varying in different parts of the arc. The resulting analyses are in effect inefficient and not based on reality when it comes to road maintenance data.

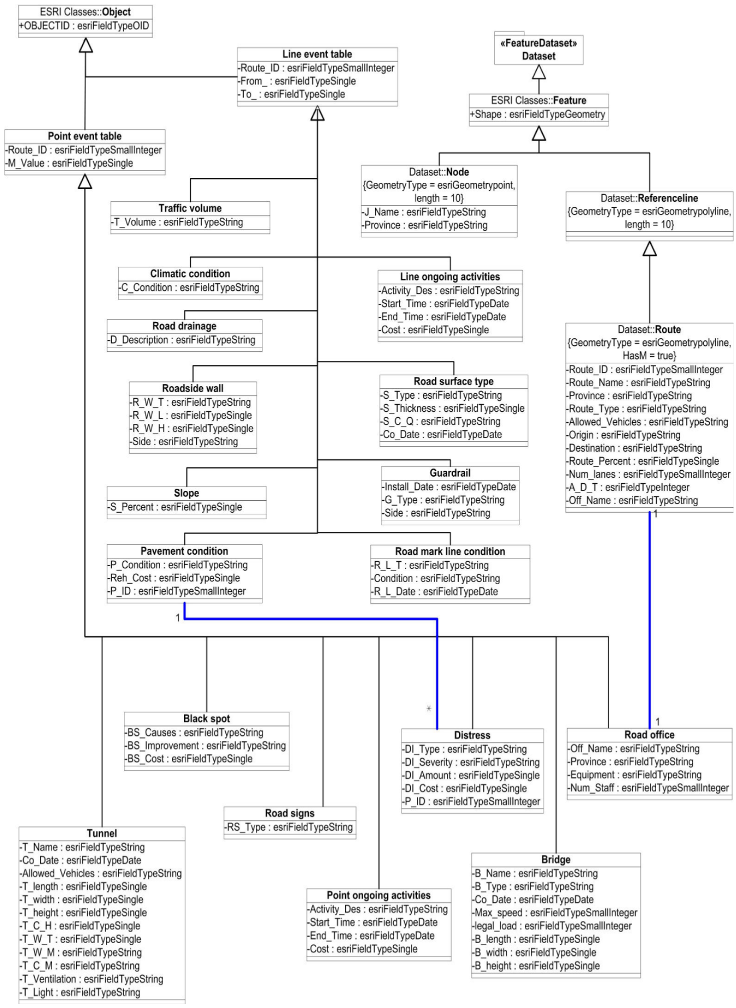

Figure 3-4: Logical Road Maintenance Data Model
Source: Jelokhani-Niaraki et al. (2009)

Objective three (3) of this Research sought to propose a road maintenance data model based on the maintenance data requirements in the RIM sector of Uganda. Research question (iv) assessed the nature of the data used in road maintenance decision making and addressed how effectively the data could be represented in a GIS and Research question (v) defined the most appropriate GIS-T data model for RIM in Uganda. Because road maintenance data is basically dealing with condition attributes that are constantly changing due to several factors affecting the road, a dynseg data model is obviously unique in analysing road condition data as requirement for maintenance decision making.

Zhu and Jiang (2009) developed and implemented a new extended arc-node data model using Dynseg technology in urban GIS-T. In this model, the arc-node linear referencing system was used for the urban roads. This was attributed to the more complicated situation in the urban areas characterised by short sections, many intersections and no obvious mileage marks along the roads. Because of this, urban transportation information is diverse, massive and multi attributed and its visualisation is highly dependent on the structure of the data adopted (ibid). Because of the challenges prior attributed to the traditional arc-node data model, the urban roads transportation attributes information were separated from arc-node topology structure and a choice made for the suitable linear reference system and method, i.e. extended arc-node. In Figure 3-5, numbers represent nodes and letters represent arcs. Figure 3-5 (a) shows an established arc-node static model with topology analysis to the road network. Its arc-node relationship is shown in Table 3-2.

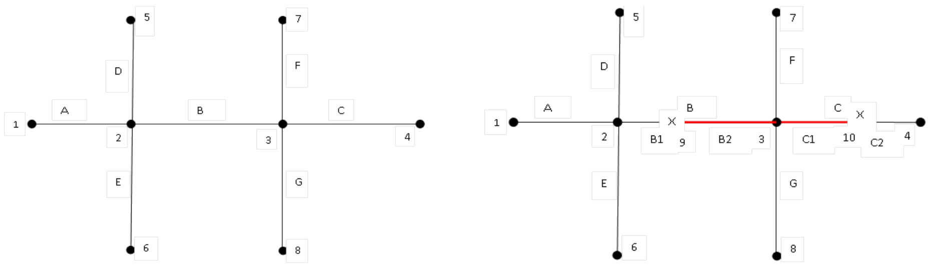

Figure 3-5 (a) Traditional Arc-Node Model and (b): Extended Arc-Node Model
Source: Modified from Zhu and Jiang (2009)

Table 3-2: Arc-Node Relationship for Figure 3-5(a)

Arc ID	A	B	C	D	E	F	G
F-Node	1	2	3	5	2	7	3
T-Node	2	3	4	2	6	3	8

Source: Zhu and Jiang (2009)

The extended arc-node model with dynseg is shown in Figure 3-5(b). In this figure, the accidental locations displayed by sign X require to be displayed on analysis without changing the arc-node topology or increasing the number of nodes. Adaption of the dynseg technology comes in handy as the traditional arc-nodes model cannot realise this instance. In effect, a new data type, link, is introduced on the basis of extending the arc-node model to match the dynamic section of the system (Zhu and Jiang, 2009). This link doesn't represent coordinates but the start and end positions of arcs in the dynamic section. The geometry of the arcs can be calculated using coordinates of the F-Dnode and T-Dnode.

Table 3-3 shows the link dynamic arc-node relationship of Figure 3-5(b).

Table 3-3: Link -Dynamic Arc-Node Relationship for Figure 3-5(b)

Arc ID	A	B	B	C	C	D	E	F	G
Link ID	A	B1	B2	C1	C2	D	E	F	G
F-DNode	1	2	9	3	10	4	2	6	3
T-DNode	2	9	3	10	4	2	6	3	8

Source: Zhu and Jiang (2009)

With this structure, dynamic expression and analysis of multi-attribute dynamic information could be realized hence the increase in flexibility and efficiency of GIS-T. This arc-node reference method was defined basing on:

1. The arc name and offset distance as the reference factors,
2. Individual digital line segments as the spatial data and,
3. The road name, start point distance, end point distance and general attribute data as the attribute data.

Even though logically fitting to have this data model for an urban entity, this Research is developing a data model for a whole roads maintenance sector in the Country. The choice of the arc-node referencing system would not serve the national roads for example, since they are highways for a large percentage of their spatial location. They are not composed of as many nodes and arcs/sections to guarantee the use of the said linear referencing system. Additionally, even when extended, the arc-node model is still cumbersome to deal with as it requires constant overseeing and maintenance of the arcs and nodes.

3.2.5 Transport Management

Since the recent developments in transportation and logistics, Intelligent Transportation Systems (ITS), Just in Time (JIT), Dynamic Vehicle Routing (DVR), scheduling, etc., are made more technically feasible and attractive. DVR is concurrent definition of routes or schedules based on information updates while its static counterpart determines routes and schedules basing on pre-defined information. This is one of the areas where research in transportation has proceeded. A framework for integrating information for DVR and scheduling using GIS and ITS was described by You-Ning at al. (1999). The motivation for the framework arose from the increase in personal travel and transportation of goods between cities accruing from the then rising economic growth and increasing urbanisation. This was causing many environmental and social problems of air pollution, accidents, noise and economic challenges of production costs, travel times and energy consumption. The rapid advances in related technologies like the GPS have contributed to implementing DVR and scheduling systems. This system involves an information intensive decision making process that integrates vast amounts of multiple and heterogeneous data. The data is classified based on its source, certainty, form and variability. The aim of the integrated framework was to accommodate both geographic features and traffic information relevant to DVR within one seamlessly articulated environment. GIS made this possible by taking charge over the geographic features and management of traffic data. It performs a major role in spatial information based complex DSS such as vehicle routing and scheduling systems by increasing performance and flexibility. The information required for dynamic VRS and its variability is presented in Table 3-4.

Table 3-4: Related Information of Dynamic VRS

No.	Information	Variability
1	Road Geometry	Static
2	Road Length and width	Static
3	Address/ post code	static
4	Speed limits	static
5	Road works	dynamic
6	Road incidents	dynamic
7	Historic link travel times	static
8	Real-time link travel times	dynamic
9	Historic intersection times	static
10	Dynamic traffic flow conditions	dynamic
11	Fleet vehicle numbers	static
12	Fleet vehicle Locations	dynamic
13	Fleet Vehicle Capacities	dynamic
14	Customer locations	dynamic
15	Time Windows	dynamic
16	Loads (Size, Weight or value)	dynamic
17	Geography of delivery region	static
18	Public activities/Weather	dynamic
19	Safety Requirements	static

Source: Extracted from You-Ning et al. (1999)

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 to the lack of utilisation of the Automatic Vehicle Location (AVL) technology. If less pricey policy measures of e.g., each vehicle possessing a seat belt per passenger are not successful in the Country, GPS technology may still be a long way to come by. Nevertheless, in Siddeswar's (2003) study, GPS technology is effectively used for Automatic Vehicle Location (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. A conceptual view of this system is shown in Figure 3-6.

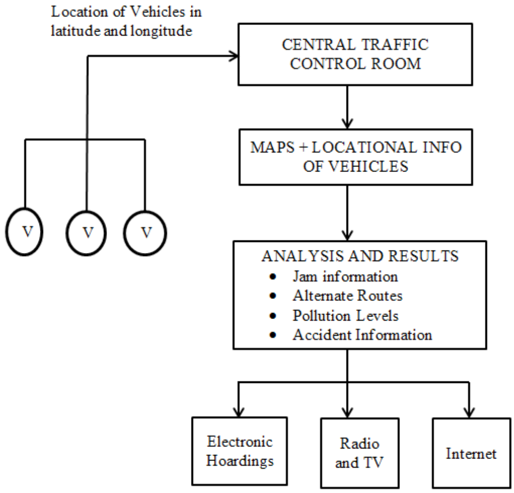

Figure 3-6: Conceptual System Automatic Vehicle Location System
Source: Siddeswar (2003)

Additionally, some of these data can be mined to be very useful later as decision support for other applications such as traffic planning, evaluation and management of black spots. This aspect of mining data is in harmony with the Knowledge Based System (KBS) as suggested by Tsou et al., (2000). Siddeswar (2003)'s illustration of GIT use was specifically targeting traffic monitoring, while, this Research has explored RIM, both as aspects of road transport management but handled in different contexts.

GIS was successfully used in the evaluation of accident black spots on roads as depicted by Gupta and Mandloi (2003). Data on the road infrastructure of the study area could be readily availed and each of the attributes was assigned weights ranging from 0-10 with the factors tending to increase the probability of accidents having lower weights. 11 factors were used namely:

1. Number of lanes in each direction,
2. Approximate number of vehicles per day,
3. Width of the road,
4. Type of the road,
5. Drainage facilities,
6. Surface condition of the pavement,
7. Frequent vehicle type on the road,
8. Presence of shoulders,
9. Presence of edge obstructions like advertising hoardings, trees, etc. very close to the road,
10. Provision of median barriers to channelize the traffic, and
11. The presence of ribbon development near roads.

For each of the roads in the study area, the total attribute weight was computed as

$$\text{Total attribute weight} = \text{(individual weights)} \times \frac{100}{110}$$

And then assigned to ranges according Table 3-5,

Table 3-5: Prioritization Scheme

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

Source: Gupta and Mandloi (2003)

The need for a similar model in the situation of Uganda cannot be overlooked. However, no maintenance jurisdiction has all its roads condition attributes captured and updated within the existing GISs. Given the background to this Research, it is clear that without the institutionalisation of GITs even such a model developed in the present circumstance may be more of a bookshelf invention.

3.2.6 Road Information from Aerial and Satellite Imagery

Spatially accurate and up-to-date road network information is crucial for numerous reasons. Most importantly, it facilitates informed decision making based on the most recent datasets. However, these databases do not exist for many areas, particularly those with rapid expansion. RS provides a means by which large areas may be mapped and detail updated with a high standard of accuracy. Extracting of the road network from high-resolution satellite images, especially in urban areas, is one of the potential applications of RS. In fact, it is the focus of research in many road applications using RS. This technology is predominately used for capturing and updating data for GIS (Wenzhong and Changqing, 2002). The updating of road network databases is crucial to many GIS applications such as navigation, urban planning, road maintenance, traffic management, emergency handling, etc. Ordinarily, land surveying was used but this is quite cumbersome and costly, and especially, when the world is advancing in ICT, the maximum use of GITs poses tremendous advantages associated with efficiency. For road condition survey and analysis however, even with the advances in GIT technologies, the predominant method of data collection is still largely based on extensive field observation by experts. GIT data products in this area are mainly supplementary for update purposes.

RS primarily evolved from the techniques of analog aerial photography. This explains why research for road extractions from imagery dates back to when it was just aerial photographs in existence. Today, RS applications are more developed than its aerial photography counterpart as much more information can be derived from the former's products. This is based on the fact that the image registration is dependent on electromagnetic (EM) radiation reflected or emitted by the object under study. This registration of EM varies depending on a number of things related to the sensing sensor, weather, time of day, and the object of study among others. In the review of the following applications, in-depth RS and aerial photography techniques will not be discussed, but only highlighted as the intention is to demonstrate the extent to which research has evolved.

The number of researches where aerial photography and RS imagery have been used as applications in the extraction of road information is large. Klang (1998) used a number of RS techniques for data processing (Ziplock snakes) from which he developed an automatic procedure for detection of changes between existing road databases and newly registered satellite imagery rectified to an orthophoto mosaic. An orthophoto, also known as orthophotograph or orthoimage is an aerial photograph which has been geometrically corrected /orthorectified so that the scale is uniform throughout the photo. The orthophoto has the same projection distortion effect as a map. Mayer et al. (1998) similarly exploited the scale-space behaviour of roads in combination with the geometric constrained snake based extraction, using ziplock snakes, as an approach for automatic road extraction in aerial imagery.

Trinder and Wang (1998) used what is termed as 'knowledge based road interpretation' to extract roads from aerial images. Knowledge base basically refers to some kind of a background on how the road exists in an image. The result was a road model including the geometric and radiometric properties of roads and the relationship between roads in low and high resolution images. A hybrid control strategy was used in which hypotheses of roads were generated in a bottom up process and a top down procedure applied to verify the generated hypotheses (ibid). This strategy involved the formulation of rules in PROLOG (PROLOG is a programming language) from the geometric and radiometric properties of the road and facts from the structures and relationships between roads in the low and high resolution images. These derived rules and facts were then stored in the knowledge base. The hypotheses of roads were generated by applying the corresponding rules to derive facts (ibid). The structural information of the road surface and the topological information of the road networks were used to remove the ambiguity of the generated hypotheses. Missing segments for example were predicted in the process of using the topological information for verification. Trinder and Wang's (1998) study tested an image in Hunter Valley, New South Wales and indicated the success in extraction of the road network using the proposed method.

Initially, attempts to detecting roads from imagery date back to 1976 when Bajcsy and Tavakoli (1976) examined Landsat-1 MSS images using the Digital Number (DN) values of individual bandsto detect the road. Notice that the DN values depend on so many factors including the spectral properties of the object, season, time, and weather condition of photography and processing conditions of images. This certainly did not yield reliable results as the same object could have different DN values in different images. Notice also that the 2 approaches by Klang (1998) and Mayer at al. (1998) combined the snake based extraction of roads with other parameters (orthophotograph and scale-space behaviour of roads respectively) for effective road extraction. This clearly communicates the need for research to further the use of technologies (aerial photography and RS in this case) for informed decision making

A system for automated road data verification using digital image processing for extracting roads from aerial imagery and topological analysis was presented by Gerke et al. (2004). The intention was to reliably and efficiently optimise the entire process of verification of the existing data other than the manual comparison process of vector databases with remotely sensed imagery. Similarly, this process is dependent on prior knowledge of the road's existence, its geometry and attributes.

Using multi view aerial imagery, Hinz and Baumgartner (2003) managed to automatically extract urban road networks. They integrated detailed prior knowledge about the roads and their context using explicitly formulated scale dependent models in order to deal with the high complexity of the multi view aerial imagery type of scenes. Figure 3-7 shows the strategy adopted in their study. As is the norm with data acquisition in urban areas, motivation for their research was mainly the need to acquire and update data for GIS.

Mena (2003) argues that automatic extraction of objects from digital imagery is not only scientifically challenging but also of major practical importance for data acquisition and update of GIS databases or site models. In search for a state of the art automatic road extraction for updating a GIS, Mena (2003) made an analytical survey based on over 250 references on the topic, which he asserts should serve as basis for collaborative research in the area. The survey details main approaches on general methods of road network extraction and reconstruction, road tracking methods, dynamic programming and snakes, multi-scale and multi-resolution methods, stereoscopic and multi-temporal analysis, hyper spectral experiments and other road extraction techniques. The analysis of methods was based on an understanding of the predetermined objective, the extraction technique applied and the type of imaging sensor utilized. He urges readers to consider his works as a subjective interpretation of the actual research state on automatic road extraction.

In the study of applying RS 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 Multispectral 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. In the study undertaken by (ibid), the spatial resolution of data was found to contribute more to the visibility 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 visibility of the road in the satellite imagery. These observations by Manzul et al. (1999) are issues of concern today and numerous research is being conducted to device solutions accordingly.

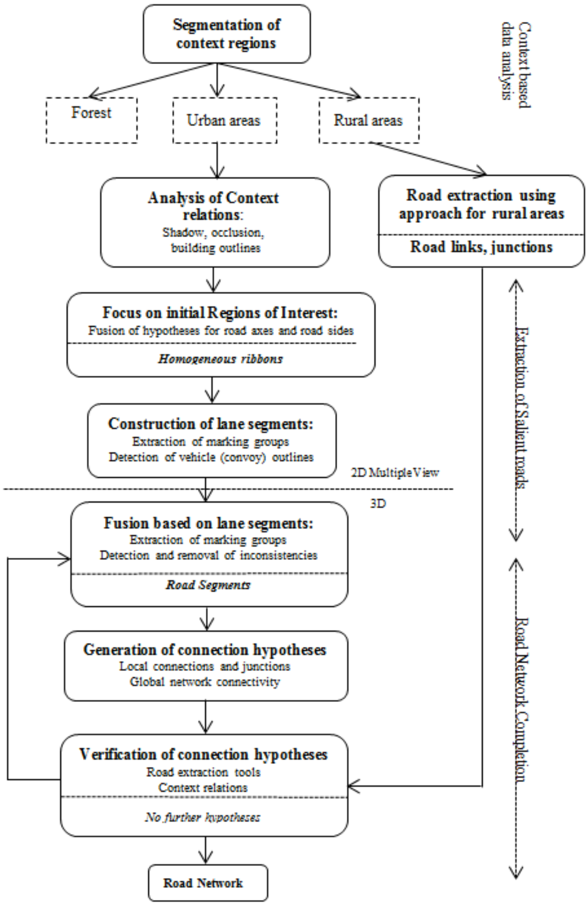

Figure 3-7: Extraction Strategy for Urban Areas
Source: Hinz and Baumgartner (2003)

Image updating based on feature extraction from RS imagery has become even more important recently because of the high spatial resolution (1-4 meters), fast orbit repeatability, rich multi-spectrum information and stable, affordable acquisition cost of satellite imagery (Zhang and Couloigner, 2004). Zhang and Couloigner (2004) highlight, that this communicates the need for the realization of cartographic and topographic data using imagery as an important application in the earth sciences. A number of researchers, including Wang and Newkirk, 1988; Donald and Jedynak, 1996; Mayer et al., 1998; Tonjes and Growe, 1998; Tupin et al., 1998; Hinz and Baumgartner, 2000; Mena, 2003; Song and Civco, 2004; Zhang and Couloigner, 2004; Jin and Davis, 2005; Mena and Malpica, 2005; and Zhang and Couloigner, 2006 present methodologies and frameworks for image-based road network extracting. Additionally, Barzohar and Cooper, (1996) presented an automatic approach to searching for main roads on aerial images by using statistical techniques. Gruen and Li (1996) developed a road extraction approach by seed points and B-spline curve, both

RS software procedures. This, like most approaches, was based on change detection where three tasks were sequentially performed:

1. Road extraction from imagery,
2. Road change detection and
3. Updating and spatio-temporal modelling.

The proposed frameworks are more or less an improvement from one to another with additional analysis techniques amongst them. An example of the proposed frameworks is an operational road database updating system by Zhang and Couloigner, (2006) shown in Figure 3-8. A multi-resolution analysis approach was used in this framework combined with novel road junction detection for road extraction. The proposed methodology by Zhang and Couloigner (2004) was tested on updating the Canadian National Topographic Database (NTDB) based on road extraction from RS imagery.

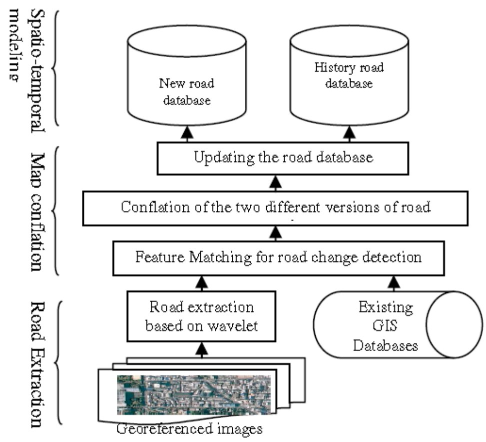

Figure 3-8: The Proposed Framework for an Operational Road Database Updating System
Source: Zhang and Couloigner (2004)

Additionally, the line segment match method based on the characteristics of images, knowledge about the road networks and related mathematical models was used by Wenzhong and Changquing (2002) for extracting road networks from high resolution satellite images. Christophe and Inglada (2007) also proposed a simple, fast, robust and efficient geometric method with very few parameters as a first step extraction level of roads from high resolution satellite images. The results of (ibid) are recommended as an initialisation for other algorithms or as a starting point for manual road extraction. Their algorithm is limited by image resolution and noise, a restriction faced by many of the RS imagery applications in Uganda and world over.

Over all, as prior mentioned, for a developing Country like Uganda, where the cost of up-to-date RS imagery is not affordable, research should primarily focus on devising 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 RS software, which at present are also a restraint to come by due to the limited expertise in the transport sector of the Country. This still puts this Research in perspective in argument there is need for a framework to strategize how all these envisaged challenges in using GIT can be dealt with.

3.2.7 Spatial Decision Support Systems

A DSS is defined as an approach or methodology for supporting decision making. **Spatial Decision Support Systems (SDDS)** developed in parallel with DSS. They are an interactive, computer-based system designed to support a user or group of users in achieving a higher effectiveness of decision making while solving a semi-structured spatial problem. "They provide a framework for integrating database management systems with analytical models, a graphical display and tabular reporting capabilities, and the expert knowledge of decision makers" (Denshamn, 1991, p. 404). GIS has supported the design of several SDSS. A SDSS is different from a GIS - in fact SDSS typically consist of GIS and DSS.

Wu et al. (2001) have designed SDSS for the analysis of route choice in congested urban road networks. Their contribution is centred on the argument that, urban congestion patterns have become omnipresent and complex all over the world such that static traditional approaches have ceased in adequacy to analyse network flows and conduct minimum cost routing. They discuss their use of GIS as a decision support tool for modelling dynamic network congestion, which involves Dynamic Traffic Assignment (DTA) and conducting minimum cost routing. Their system predicts network flows at a detailed level of temporal resolution while capturing dynamic congestion propagation effects. GIS's database management capability that caters for geographical user interfaces and cartographic visualisation capabilities allows effective decision back up that supports 'what if' scenarios for strategic and tactical planning & management. For instance, in support of 'what if scenario modelling' the system can assess the impact of unplanned network disruption on network congestion, routing and estimated arrival times (ibid). The work of Wu et al. (2001) earmarks the ITS analogy which they contend offers some promise in capturing realistic depictions of urban network flows. ITS can only report on traffic conditions in near real-time and do not forecast future flows resulting from changes in land use, infrastructure, transportation policy or demographics (ibid).

A SDSS was also used for the analysis and evaluation of different transport policy measures by Arampatzis et al. (2004). Arampatzis et al. (2004) argue that despite the obvious importance of using transport models for evaluating urban transportation policies, their development and application in empirical settings often face critical obstacles. The difficulty relevant to their research was the need to manage the spatial data required for an urban scale transport modelling. This data includes the origin-destination zoning system, the aggregate travel demand for each zone and the transport network for each travel mode (ibid). Frequent updates to the database are dictated by the need to evaluate 'what if' scenarios and the dynamic nature of urban environments. This is coupled with the problem that the conventional strategies for evaluating urban transportation modal share and traffic assignment policies apply sequential modelling of the 4 transport model components. This approach is known to be computationally complex, tedious and produces inconsistent and non-convergent results among the individual components. The massive nature of the results required effective database management and an insurance of database integrity after updates are made. Due to its extremely significant power in transport modelling, GIS was earmarked for enhancing the role of the transport model as a SDSS. It facilitates the efficient and portable spatial data storage, processing, model accessibility, database maintenance & updating and cartographic display of model results. GIS can greatly improve the realistic representation of the multi-model network data model, effective user interfaces and efficient visualisation of network equilibrium solutions (Peng, 1997) as cited by Arampatzis et al. (2004). The two policy measures were; one concerning the extension of the region where half of the private cars are prohibited from entering into the municipality of Athens and the other was evaluation of the reduction of parking places in the same region by 50 %. The characteristic of the decision support tool was that it predefined the two abstract policies and incorporated them as methods into the system. The methods were actually algorithms/procedures for estimating impacts of each defined policy types and thus; an 'abstract' policy became 'application specific' by the user definition of its parameter set and its geographic domain.

3.2.8 Digital Road Mapping

The advancement of GITs enables fast and cost effective acquisition of spatial data. A lot of data is collected using GPS and RS techniques and effectively stored within the GIS for decision making purposes. Today, mapping markets are experiencing tremendous expansion and rapid growth. This is because mapping science has steadily been stepped into digital mapping era where the core technologies of photogrammetry, RS, GIS and spatial positioning are becoming fully integrated (Tao, 1998). A case in point is, for road maintenance decision support, road condition inventory surveys are quite vital prior to the establishment of a road maintenance system. Also, the accuracy requirements and the amount of information necessary to build and maintain a road inventory have increased drastically in the recent years (Kingston et al., 2007). As a result, manual field measurement techniques and traditional processing methods are radically giving way to new solutions. Different road departments and researchers have shown that **Mobile Mapping Systems (MMS)** (Mobile - GIS) represent advanced techniques for dynamically inventorying road networks and their surrounding features. These systems have integrated navigation sensors, digital imagery equipment and processors to create digital maps that include both the geometry of the road and roadside assets (Kingston et al., 2007).

Developments of the mobile mapping technology have a history from photo-logging, to video logging before mobile mapping systems. "In the 1970's photo-logging systems were used by many highway transportation departments to monitor pavement performance, maintenance effectiveness, encroachments, etc." (Tao, 1998, p. 1). Film cameras were used to capture the photos through the car windshield of which the instantaneous position was determined using inertial devices such as gyroscope, accelerometers and wheel counters. However, this photo-logging methodology had some drawbacks for which the advent of video-logging took from. These included poor accuracy of vehicle positioning, only one camera configuration system, no 3D object measurement, costly and time consuming analog based storage and processing. However, today, the wide spread availability of digital cameras with GPS embedded has tried to improve the storage and processing required for photo-logging. More of these cameras can be used in combination to achieve 3D object measurements when required.

GPS video-logging superseded the photo logging systems. With video-logging, the collected video images can be georeferenced with respect to a global coordinate system by using continuous GPS navigation and positioning information. These kinds of systems are mainly used for visual inventory and feature documenting along road corridors. Then, MMS evolved from video-logging systems. They currently integrate available navigation techniques, digital 3D photogrammetry, digital mapping and GIS technology (Gilliéron et al., 2001). The common feature of MMS is that more than one camera is mounted onto the mobile platform allowing for stereo imaging and 3D measurements (Tao, 1998). MMS are equipped with multi-sensors for navigation and positioning which assist in accomplishing direct geo referencing of the digital images. The collected geometric and attribute information can for example be directly used in building and updating of road databases. “In fact, the development of MMS was largely driven by the transportation applications and is being further inspired by the wide implementation of ITS and GIS-T” (ibid, p.1).

A mobile mapping technology to enable fast and cost effective acquisition of spatial data for the road network was developed by (ibid). This system is composed of 8 black/white Charge-Coupled Device (CCD) cameras, a colour Super – Video Home System (S-VHS) camera, Inertial Navigation Surveying (INS) System and 2 GPS receivers. The GPS equipment in the system was for position determination and geo referencing of the captured video. In the VISAT mobile mapping system as it was named, multiple positioning sensors, GPS, INS and Dead Reckoning (DR) are combined for data processing to improve the accuracy and robustness of georeferencing. Like with advanced MMSs, ground control required for traditional mapping is eliminated. Coetsee et al. (1994) also present a GIS data collection technology using the GPS Van that is supported by a GPS/Inertial Mapping System hence providing an automated method for generating digital maps and also tagging these maps with locations of interest to the database.

In support for road mapping as is the case in the applications of ITS and the map update technology, Guo et al. (2007) used in-vehicle GPS trace data to dynamically generate high accuracy road maps through statistical analysis of these data. Guo et al. (2007)’s method exhibits several advantages:

1. The low cost of data collection - as it required the installation of GPS equipment in ordinary vehicles that would run on their own routine ways,
2. Flexibility - as it adopted the strategy of accumulating these data other than beforehand planning. Note that with land survey methods for example, prior planning is a requirement before collection of GPS measurements for the underlying purpose.
3. Dynamic mapping potentiality - as it implements near-real time data collection, processing, road mapping and map update.

These advantages were realised provided that the exchange networks were well constructed among the individual vehicles and data centres (Guo et al., 2007).

Inappropriate road vector centre lines were rapidly detected by Taylor et al. (2001) using GPS-GIS navigation in an algorithm known as Road Reduction Filtering (RRF). The general approach adopted in their work was that "to improve the accuracy of the computed position of a vehicle is to identify all possible candidates for the correct road and systematically remove the wrong ones" (ibid, p.198). This was achieved by map matching all candidate road segment arcs and comparing them with the trajectory described by the uncorrected point positions. This was based on the distance travelled and the bearing of the uncorrected point positions in comparison with the corresponding reference positions on the road centre-line.

Today, vehicles are acting as platforms for a number of data collection equipment some of which may be a real time requirement. The Finish Geodetic Institute has developed, as a roamer, a mobile road environment mapping system since 2003 (Kukko et al., 2007). The vehicle platform roamer consists of positioning and navigation systems among others. The positioning and navigation systems include the GPS/INS in the Synchronized Position Altitude Navigation (SPAN) that integrates GPS and inertial data for applications that require greater functionality and reliability than traditional standalone GPS. "The SPAN system also operates in RTK (Real Time Kinematic) mode with an internet based application developed by the Finnish Geodetic Institute" (ibid, p.244).

In works supported by the US Department of Transportation (DOT) under the project, 'Monitoring of Unpaved Road Condition using RS and Other Technology', an unmanned aviation mapping system – Unmanned Aviation Vehicle (UAV) was used in the monitoring of the condition of unpaved roads (Zhang, 2008). The system was basically acquiring images of the road and parameters of their condition. The UAV in Zhang (2008)'s project is a RS system for unpaved road condition assessment based on a low cost helicopter equipped with a GPS/IMU and a geomagnetic sensor to note the position, altitude and velocity of the helicopter. The helicopter was synchronised with a computer at the ground station for communication in real time as flight parameters and control mechanisms are tracked. "The entire processing system included camera calibration, integrated sensor orientation, digital 3D road surface model and orthoimage generation, automated feature extraction and measurement for road condition assessment" (ibid, p.1). Zhang (2008)'s adopted strategy for monitoring the condition of unpaved roads is a hybrid approach comprising two interrelated systems as shown in Figure 3-9. The road condition report is composed of information on the state of the road as obtained from the data of the UAV-based RS. The predictive modelling box is composed of the data from the UAV report which when combined with other terrestrial accumulated data gives rise to a predicative road condition model. "The UAV-based RS acquires road imagery with high resolution from an UAV platform, and assesses roads based on the condition parameters derived through the development of sophisticated algorithms for image processing and analysis" (ibid, p.2). With resources, these kinds of technology are effective in speedy and frequent data collection and updates. The challenge however remains the resolution of the imagery from which some road condition parameters like rutting and cracking may not be possibly achieved.

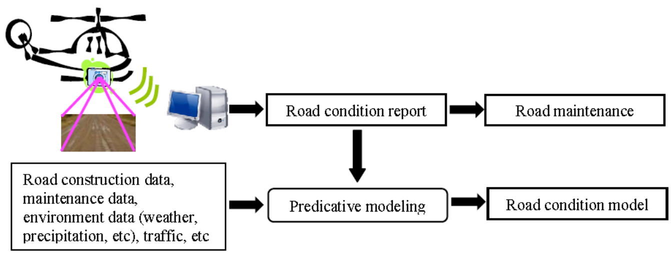

Figure 3-9: General Strategy of the Proposed Unpaved Road Condition Monitoring System
Source: Zhang (2008)

Open on the market, 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, mobile digital mapping as one. Other applications include asset inventory collection, verification, validation and auditing of existing assets, review and update of condition assessments, engineering design and assessment specifically visual inspection of network and road geometry and network operations. They capture and integrate video and GIS mapping, can incorporate third party sensors to their systems to customize data collection, and provide 2D and 3D in frame measurements. Under asset management, it has been possible to measure asset dimensions and export them to external asset management systems and GIS applications. 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 their captured video. The RouteMapper interactive internet browser integrates high resolution digital video imagery and accurate location referencing on a web-based platform. More details about the RouteMapper video surveying systems are available from their website (RouteMapper, 2009)

3.3 Related Applications of GITs

GITs have many other road applications. They have been used in enhancing road safety analyses by answering simple accident enquiries and identifying single sites with a high number of accidents. Additionally, GITs have improved the selection of routes and areas suitable for remedial treatment, identification of home locations of road accident causalities and are also foreseen as a measure to a more accurate and efficient selection of engineering measures and road safety campaigns (Austin et al., 1997). All applications in Austin et al. (1997)'s study were dependent on a number of data sources as shown in Figure 3-10.

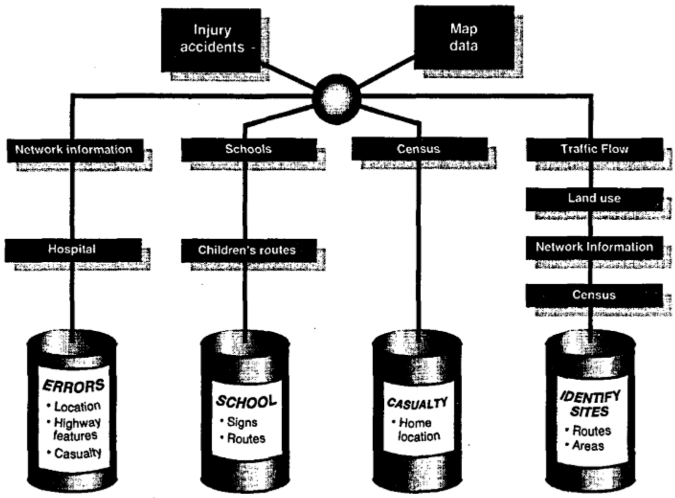

Figure 3-10: Data Sources
Source: Austin et al. (1997)

Success of all pinpointed applications is attributed to the improvements in the quantity and quality of the information that GIS can handle compared to manual standards.

An integrated GPS and GIS technology has been combined with the material and equipment (M&E) management system to reduce onsite material wastage. This was a strategy focussing on the effective coordination of materials management that included efficient purchase and ordering, just in time delivery, careful storage and use of materials to minimize loss, maximize reuse, and prevent undoing and redoing and reduction of packaging waste (Li et al., 2005). Li et al. (2005) used an Incentive Reward Program (IRP) comprising of IRP-based barcode system to provide instant and up-to-date information on the quantities of materials requested or returned by a crew to a storage keeper on site. This system was automated by integration of the barcode system with GPS, GIS and Wide Area Network (WAN) technology to facilitate the efficiency of Material and Equipment management and to control and reduce construction wastes onsite. The integrated GPS and GIS technology helps to improve efficiency and to increase profits by providing real-time vehicle locations and status reports, navigation assistance, drive speed, heading information, and route history collection (ibid).

Bubbico et al. (2004) used a GIS based approach to analyse the risks of hazardous materials on road and rail transport. GIS was used to manage information related to territories which enabled the update and accurate consideration of local area data affecting risk analysis. These territorial data included population, accident rate and weather conditions along the routes. To aid analysis this data was associated with geographic coordinates. The GIS enabled route identification and accurate transportation risk analysis for single transportation events, multiple substances, trips and itineraries (Bubbico et al., 2004).

To relate even more closely with this attested Research, Sebake and Coetzee (2012) with a focus on facilitating the development of a common National Address Database (NAD) in South Africa, evaluated the factors that motivate or hinder organisations from sharing data for address organisations in a South African SDI context. It is their hope that the results of their study as summarised in Table 3-6 guide the successful development and implementation of a single NAD in South Africa (ibid).

Table 3-6: Motivators and Barriers for Interorganisational GIS Data Sharing Initiatives

Motivators
Sharing the cost of implementation among participating organizations; improved decision making through exchange of information
Cost-effective
Improved data quality
High returns on investment
Reduced time spent in data collection and decision making; increased data availability; More diverse or dynamic maps
Improved user satisfaction
Barriers
Institutional disincentives; historical and ideological barriers; power disparities; differing risk perceptions; technical complexity; political and institutional culture
Conflicting priorities among participating organizations; differences in GIS facilities, awareness and data handling skills; Concessions over access to information, leadership, data standards, equipment, and training
Staff turnover; lack of resources; incompatible old systems; lack of support from management
Coordination of system requirements
Lack of common data definitions, formats, and models
Differences in data quality; inadequate planning and consultation about data use; insufficient staff and technical resources
Networking costs; data confidentiality, liability and pricing

Source: Sebake and Coetzee (2012

Ehrensperger et al. (2007) studied the applications of GITs for Natural Resource Management (NRM). They argue that GITs are a prerequisite for NRM and a means of spatial analysis. The focus of their research was on the potential of GITs 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 GITs in developing countries. Ehrensperger et al. (2007) discuss the potentials of GITs for various applications ranging from 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. Their 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 established as limiting 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) stipulated the role of spatial information technologies as a gap bridging mechanism in the integration of traditional/local environmental knowledge and western science. Their efforts were in line with Agenda 21[5] 's chapter on the role and importance of information for sustainable development. Directly they focussed on the provisions made for harnessing the potential of ICT for strengthening the capacity for traditional information. Remember, 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 GITs 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. In the same sense, GITs have exercised roles in boosting the traditional field based survey methods of collecting road condition data for decision making prior to road maintenance. As prior mentioned, GITs are only a supplement to field data collection through inspections by experienced personnel.

Croswell, (1991) conducted a content analysis of 39 articles selected from major GIS and information system publications. His intention was to assess common problems and approaches for overcoming problems in GIS 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, FGDs, and observations, the approach of reviewing literature to devise strategies of successful GIT implementation is mainly utilised in amalgamation with stakeholder involvement in order to develop the methodological framework model that can be adapted with limited or no resistance.

Institutionalisation of GITs is proposed as a paradigm for studying the impact and effectiveness of GITs by Eric de Man, (2000). Onsrud and Pinto (1993); Anderson (1996); Leitner et al. (1998); Goodchild (2000a; b); as well as Sieber (2000) all have

[5] 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 organisations of the UN, governments, and major groups in every area in which humans directly affect the environment. (http://en.wikipedia.org/wiki/Agenda_21)

their contributions with some aspects of GITs, either with their adoption, successful implementation or diffusion mechanisms which are inclined to the strategies adapted and benefits expected out of this documented Research.

3.4 Research Groups

It is a widely developing idea to do research under groups or themes hence the term 'research group'. A research group is a collection of researchers working on related problems and or concepts to solve, hence, sharing and developing ideas that build on each other's research. This Research has been accomplished under the Sida sponsorship of Makerere University under the theme - Sustainable Technological Development in the Lake Victoria Region, Uganda. Within this broad university theme, there exist a number of sub theme programmes defined by the broad category of research accomplished there in. This Research falls under two sub programs 1. ICT and GIS for sustainable development and 2, Infrastructure management. Under the infrastructure sub programme, the Research is 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 part of ICT-GIS, the Research 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 framework strategies to accentuate the use of GITs including capturing and management of RIM data, particularly condition inventory, which in turn should effectively be sharable and useable for decision support amongst the relevant organisations.

At the Swedish University, Blekinge Institute of Technology (BTH), the Study resides within the ICT4D (ICT for Development) subprogram and is inclined to the methodological epistemology shared by the Department of Technoscience. This is in reference to the adapted participatory research methods of enquiry involving triple helix arrangements.

3.5 Concluding Remarks

Majority of previous research in the area of GITs as decision support tools has focussed on the development of customized GIT models and systems for several transport applications. In all the attempts, data have been readily availed or easily collected using the target GITs for the respective study areas. It has also been observed that in many of the reviewed contexts, data sharing frameworks and collaborations are effective.

On the other hand, this Research focussed on developing a sustainable approach to using GITs for RIM in a situation where data is not readily available. The Research has defined a methodological framework composed of strategies to accentuate the use of GITs in acquiring up-to-date data and utilizing it for informed decision making. This is the dilemma facing road infrastructure planners and managers in Uganda. The most immediate problems in Uganda are not systems but the capability to initially 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 will be more applicable as decision support tools.

CHAPTER FOUR
METHODOLOGICAL CONSIDERATIONS

4.1 Introduction

This Chapter details the methods used to assess the gaps and limitations to accessing GITs in road maintenance, devise strategies to enhance the use of GITs in road maintenance and define a GIS-T data model for road maintenance in Uganda. Methods including but not limited to literature review, interviews, field observations & measurements, FGD, workshop and conferences were applied in a cross sectional manner to ensure complementarity of findings. The Research initially involved the identification of stakeholders in the road maintenance sector. The adopted methodology was participatory, as the identified stakeholders were participants in the Study. In the following sections and sub sections, details on how the stakeholder identification was performed are discussed, the research methods used are elaborated and analysis techniques of the obtained data streamlined.

4.2 Stakeholder Identification

The first stage in data collection was identification of the organisations that have stakes in maintenance of roads in the Country. Much of this information was collected from the MoWT, which is responsible for the Country's general road network. Within the environs of the ministry, a review of documentation on road management and maintenance was undertaken, from which other organisations were identified for inclusion in the Study. Upon identifying these organisations, the role played by each was assessed. Personnel involved in decision making in these organisations were identified.

Organisations like the National Forestry Authority and Uganda Bureau of Statistics (UBOS) that were not directly involved in road maintenance, but are custodian to GIS roads datasets were eliminated from further involvement in the Study. Only their datasets were analysed to access gaps and limitations. For other organisations that had GIS systems in establishment, their datasets were obtained, some with constraints, for analysis and comparison with datasets from the rest of the stakeholder organisations.

Basically, four datasets were used in this Research- one from UNRA obtained through PROME Consults, the district road dataset from MoWT, the UBOS dataset and datasets from Kagga & Partners private consultancy. The intention of this was to access the quality, standards, semantics and any other concerns as would arise from the data in use.

4.3 Data Collection Methods

4.3.1 Literature Review

There is literature documented in organisational reports, journal articles, conference proceedings, PhD theses, books, reports, magazines, online (non-proprietary), entrepreneur company websites, etc., on the applicability and implementation of GITs, challenges with GIT implementations, diffusion of GITs, GIS-T data models, etc. This literature was continuously and consistently reviewed in order to give context to this Research. Subjects relating to the use of GITs including but not limited to digital photography, RS, GIS, GPS, ground based mapping and cartography as decision support tools, their institutionalization, adoption, implementation, and success factors, management of RIM and works, road maintenance data, data models and standards and all other material in line with modelling GITs for decision support were reviewed. At the end of each article, book, report or magazine reviewed, cited references were also obtained for further review. This process was continuous until the content of the material became dilute for the Research context. The content of these documents was analysed and used for purposes of this Research. This literature was obtained mainly from google scholar, Makerere University, Uppsala and BTH University catalogues, the identified organisations involved in road maintenance in the Country and independent search engines like the engineering village. The access to the obtained literature is attributed to the subscription of Makerere University and Blekinge Institute of Technology (BTH) libraries to many of the online journals, and the availability of internet at these institutions.

4.3.2 Interviews

In order to perceive the gaps and limitations to accessing GITs in road maintenance and to devise strategies to enhance the accessibility of these technologies, information on the existing systems within the organisations was paramount. The perception of gaps and limitations from literature together with the knowledge of the existing systems in the said organisations invoked ideas on the requirements for the incorporation of GITs in road maintenance applications. All these were acquired through interviewing the responsible personnel among other methods.

Initially, FGD were held at each of these organisations. This was intended to identify the competence of the individuals for key informant interviews and to give an indication on how the interviewing will be conducted to ensure that the right data was obtained. Key informant interviews using an interview guide (see Appendix 1) were conducted with the road engineers, managers and GIS specialists in these identified organisations. During these interviews, other knowledgeable personnel both in road maintenance and GIT applications in the discipline, as earmarked by the interviewees were identified for inclusion into the Study. Long interviews were recorded and transcribed for further analysis.

Questions relating to the data used for road maintenance, how the data is collected and managed, the frequency of data collection, etc. were posed. For purposes of pretesting and developing a more precise interview guide, informal sessions were initially organized with only a few questions prepared. The intention was to evoke more questions based on the responses of the interviewees. For this pretesting session, five (5) persons were interviewed using the designed guide and during then, the guide was accessed in terms of clarity of questions, interview time and whether all the required parameters were included in the guide. The interview guide was continuously updated until a moment when found satisfactory. Even though pre-tested, much of the interviewing was dependent on the interviewee responses and their varied schools of thought.

Where the number of these personnel was large, for purposes of having a manageable size of interviewees, sampling was performed. Altogether a combination of expert and snowball sampling techniques were used to identify persons with knowledge and demonstrable experience and expertise in GITs for road maintenance. These then recommended others who also met the criteria for inclusion to the interview. The sampling frame comprised of managers and GIS experts in the identified organisations. The sample size was set to 3 persons per organisation although in a number of organisations, only one would be informative of the subject matter in addition to willingness to be interviewed. This was a limitation to balancing the number of participants per organisation. For UNRA however, 5 personnel were interviewed. This is because, in UNRA, GITs are being appreciated at a faster rate today, giving rise to a higher number of personnel interested and involved in the concept. The result was that a total of 23 persons were interviewed across all the organisations. As the number of contractor and consultancy companies in the Country keeps growing, and yet their knowledge, use and perception of GITs for road maintenance are on the low side, the choice for inclusion into the Study was subjectively based on willingness. In consequence, only 6 of these organisations were included in the Study. These comprised of PROME, COWI Uganda Limited, Newplan Limited Consulting Engineers and Planners, Omega Contractors, DOTT Services Limited, and Kagga & Partners (KAGGA). Table 4-1 shows a list of the numbers of personnel interviewed in the involved organisations.

Table 4-1: Organisations and Personnel Interviewed

Organisation	No. of persons interviewed
MoWT	2
UNRA	5
Kampala Capital City Authority (KCCA)	1
PROME	3
COWI	2
Newplan (formerly Norplan)	2
Omega Construction	1
Dott Services	2
KAGGA	1
URF	1
Jinja (District, UNRA and Municipality offices)	3

4.3.3 Observations

Field visits and observations were made to the transport ministry and other stakeholders (UNRA, district engineers, KCCA, municipality engineers, contractors and consultancy firms) for illustrations on how decision making is made prior to maintenance of the road infrastructure. This was a cyclic process with interview coordination. Observation was made of the data used for road maintenance, the collection methodologies of these data, the structures and management of the organisations databases, the frequency of data collection and other related observations. This observation phase also gave an indication of the gaps and limitations of GIT usage and assisted in developing strategies to develop the methodological framework to accentuate the usage of GITs in the Sector.

4.3.4 Field Data Collection

Field data collection was initiated with the aggregation of all GIS roads datasets from stakeholder organisations in the Country. It was noted that various projects where GITs had been employed, had used road datasets as foundation data for their various mapping ventures. All these datasets that could be availed were collected for further analysis. This was followed by an independent mapping of a sample of roads in the Study area as a means of assessing the correctness and up-to-datedness of the digital data prior obtained. Using GPS devices (see Figure 4-1 (a) & (b)) and a laptop computer installed with the ArcGIS 9.3 desktop software, all placed within a vehicle platform, the mapping was accomplished.

Figure 4-1(a) and (b): GPS Devices Used in Field Data Collection
Source: Internet pictures

The adoption of the independent mapping of the roads methodology was to create awareness through publications and explore the potential of GITs for RIM especially for data collection and management in Uganda's context. This follows as overview of the trends in GIT use for various road applications as presented in the previous Chapter Three.

The data collection exercise involved the use of a vehicle, 2 GPS receivers (DG-100 GPS Data logger + receiver and BT-359S Bluetooth GPS receiver), for backup and accuracy precision purposes and a notebook computer (Panasonic Toughbook CF-U1 running windows XP). The two GPS devices used were of the same accuracy details of which are shown in Table 4-2.

Table 4-2: Accuracy of the DG-100 and BT-359S GPS Device4

Accuracy	
Horizontal Position	10 meters, 2D RMS 1-5 meters 2D RMS, WAAS corrected
Velocity	0.1m/sec
Time	1 micro-second synchronized to GPS time

The Root Mean Square (RMS) relates to standard deviation. Wide Area Augmentation System (WAAS) is an air navigation aid developed by the federal aviation administration to augment GPS data. It corrects for GPS signal errors caused by ionospheric disturbances, timing, and satellite orbit errors.

The GPS loggers were synchronized with the GIS on the notebook computer to allow for tracking of the vehicle path along the road sections traversed. Since the elimination of selective availability in May 2000, these GPS devices have been found to provide highly accurate GPS locations, which, for the assessment of the existing roads datasets was sufficient. Selective availability was a deliberate introduction of errors into GPS signals so as to downgrade the ability of civilian GPS receivers to determine locations. However, since the US government discontinued the use of selective availability, GPS systems have become even more accurate by an approximate factor of 5.

Additional products including a satellite image of the Study area and the existing road datasets in custody were overlaid together during this data collection phase. The satellite image was downloaded from the internet using the Global Land Cover Facility (GLGF).This facility is a centre for land cover science with a focus on research using RS satellite data and products for assessing land cover change. These datasets are free for anyone via FTP with compressed images of ETM+ including all bands and having a size of 180 MB. For users not interested in image processing, a mosaic covering ½ the Country is about 270 MB (GLCF, 2012).

GIS analysis of these data was performed to boost the findings on the gaps in the data archived in the road maintenance organisations. Through this method of data collection, a low cost GIT based methodology for preliminary road maintenance decision support was also formulated. This methodology was presented at the conference on recent advancement in Geomatics Research, at Makerere University (Kayondo et al., 2011b). A summarized re-presentation of the same is made in Chapter Five. Still in line with this mobile mapping methodology, sections on GIT methodologies and products, together with the potential of GITs, have been included in Chapter Five. The adaption of the above methodology and the availability of various GITs embedded equipment as is presented in Chapter Five, instituted a couple of GIT potentials for which the road maintenance sector should be able to benefit.

4.3.5 Workshop 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. Due to ethical considerations in the Research (see section 4.4), it was not possible to attend these workshops and conferences. However, reports from these gatherings were shared and internalised by the researcher. This boosted inputs for the methodological framework and grounded the gaps and limitations in GIT use on the other hand. Additionally, the researcher has made presentations on the PhD work in progress at a couple of internationally organised conferences. The reactions and discussions accruing from these presentations generated an input to the findings of the Research.

In order to maximize stakeholder participation and consent on the findings and suggestions in place, a workshop of 30 participants was held on 11th August 2011. The intention was 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 RIM. The participants included members from the RIM stakeholder category that had prior been identified, scholars and professionals in the discipline. The Researcher presented the Research findings and recommendations to that date. The stakeholders then had an opportunity to react in a discussion. From this interaction, harmonized input into the researcher's evolved methodological framework was achieved by virtue of the increased stakeholder participation.

4.3.6 Data Modelling

The last objective of the Study was to develop a GIS-T data model for road maintenance in Uganda. The methodology adopted for this stage of the Research involved three integrated procedures:

1. Identification of the road maintenance data requirements,
2. Understanding and consideration of the IQL data categories, and
3. Review of existing data models and standards in transportation.

The identification of the road maintenance data requirements was mainly through document & datasets review, observations and interviews as prior discussed. The existing datasets as obtained from the numerous stakeholders were also analysed basing on the SDI components prior discussed. The underlying questions in these analyses included:

- What data is necessary and available for road maintenance applications?
- How should the data be organised?
- What additional data will be required?

The understanding and consideration of the IQL data categories entailed generating knowledge of the various data views at the different levels of decision making.

Upon reviewing existing data models and standards in transportation, the research questions relating to the nature of road maintenance data, its effective representation in a GIS, and the most appropriate GIS-T data model for road maintenance were addressed.

A conference paper on a GIS-T data model for road maintenance in Uganda was presented at the conference on the recent advances in Geomatics Research (Kayondo et al., 2011a). This paper was based on a review and analysis of the existing GIS-T data models and standards in line with road maintenance.

A combination of data and method driven approaches was used in modelling the data structure. With the data driven approach, the focus was on the existing data and its properties. In the method driven approach, the various activities within the sector were used to model the structure according to user requirements.

For their flexibility, widespread nature and ease to read in modelling the world, and the possibility to present substantial groups of high level classified entities of the road in a very expressive language, **Entity Relationship Diagrams (ERD**) were used to present the conceptual data model using an integrated top-down and bottom-up approach. Besides logically sketching the conceptual classes from the conceptual data model, the ESRI provided template in Microsoft Visio 2007 was used for representing the logical model tables and their relationships. Further details on this model are presented in Chapter Seven of this Thesis.

4.4 Ethical Considerations

The road maintenance sector in Uganda has always been in the limelight over the unworthy condition of roads, and accountability of maintenance funds among others (Musinguzi, 2011 and Mugerwa, 2012). This situation has caused various types of resistance from organisations involved in the sector including participation in research activities. The strategy adopted to convince the organisations that were included in this Research was ethically derived. In effect, all ethical rules, regulations and laws have been adhered to during the execution of the above research methods. For instance, the author made clear of her identity during observations. However, this role and self-divide was acknowledged by the author in order to obtain ethically correct information. Similarly, in the presentation of gaps and limitations, names and organisations that preferred to remain anonymous have not been mentioned. As it was not agreeable that a researcher attends workshops organised by the road maintenance sector, this was obliged to. Instead, documentations of the workshop proceedings were availed and analysed for research purposes. The sources of these documents have remained anonymous in the Thesis.

4.5 Data Analysis

Two major approaches were adopted for analysis of the collected data from the Study-qualitative and GIS data analyses.

4.5.1 Qualitative Data Analysis

The gathered data from interviews, FGD and some observations was analysed using content analysis. Generally, the qualitative analytical procedures implemented included categorisation, abstraction and interpretation. Much of these data was either transcribed from the saved voice records or recorded as guide notes by the researcher. This was in addition to the documents and records collected from the various organisations. The other sources corroborated with interview results included:

- Field data sheets for the engineers,
- Annual work plans for road maintenance,
- Progress reports on maintenance tasks,
- Project proposals and terms of reference,
- Video recordings of road inventories,
- Photographs of road sites and bridges,
- Email exchanges and SMS messages,
- Etc.

Themes were generated based on SDI concepts, the principle of causality, interview responses and conference discussions. These themes included:

- Involvement of GITs in organisational activities,
- Institutional arrangements and partnerships,
- Data sharing and collaboration,
- Data standards,
- Software compatibility,
- Policy issues,
- Budget limitations,
- Geospatial capacity, and
- Linear referencing approaches.

It was on the basis of the content under the above defined themes that it was possible to:

- Categorize the gaps and limitations in the use of GITs for RIM, and
- Devise strategies in form of a methodological framework to accentuate the use of GITs as decision support tools in RIM.

4.5.2 GIS Analyses

Various GIS analyses have also been performed on the data. The collected GPS data during the Study was overlaid with several GIS road datasets of the Study area. Analyses through both vector overlays and raster processing using satellite imagery was accomplished. This was as an attempt to access the quality of data in use for maintenance vis-à-vis the independent field measurements (GPS locations of the road centreline) collected by the researcher. Additionally, attribute and spatial queries were used to generate statistical summaries of the road inventory and condition data from the existing datasets.

The findings from the above research methods have been discussed in Chapter Five, and also in papers Kayondo et al. (2011a), Kayondo et al. (2010) and the Licentiate Thesis (Kayondo, 2011).

Table 4-3 shows the 5 research questions and methods used to address each. The symbol (√) indicates that the given research question was addressed using the assigned research method.

Table 4-3: Research Questions vs. Research Methods

	Research Methods						
Research Question	Literature Review	Interviews	Observations	Field Measurements	Documents review	Workshops and Conferences	Data Modelling
• Actors in RIM and barriers in GIT use	√	√	√	√	√	√	
• Potential and opportunities of GITs	√	√		√	√	√	
• Methodological Framework components	√	√	√		√	√	
• Nature of road maintenance data and its representation in a GIS	√	√	√	√	√	√	√
• GIS-T data Model	√	√			√	√	√

CHAPTER FIVE
GAPS, LIMITATIONS AND POTENTIAL OF GIT FOR ROAD MAINTENANCE – A UGANDAN PERSPECTIVE

5.1 Introduction

The use of GIT for road maintenance in Uganda is still at its infancy. It was initiated by the District Urban and Community Access Roads (DUCAR) MIS project where RAMPS was used in planning and reporting road information. As prior mentioned, this project failed to meet its pre-set objective. To boost the success of future GIT projects, it was necessary to know which organisations play what role in road maintenance. Also, the gaps and limitations pertaining to the use of GIT in RIM needed to be appraised for actions to be realised. This Chapter discusses the findings from a qualitative analysis of interviews, document reviews, FGD, field observations and measurements within the Study area. It presents the actors and roles played in RIM, gaps and limitations in the use of GIT for RIM and the potentialities and opportunities envisioned by GIT use in RIM. Strengths noted in the RIM sector in as far as GIS-T concepts are concerned are also recognized. GIS analysis of the datasets in use for road maintenance decision making was performed using the ArcGIS 9.3 software and presented herein. The analysis included assessment of the geometrical correctness of the data, standards, semantics and projection of the GIS datasets. Independent field measurements were conducted in the Study area to assess the reality of the GIS road network in existence. The mobile digital video mapping technologies, discussed in the conceptualisation chapters, were adapted for this independent mapping exercise. These mobile mapping technologies are basis on which the section on potentialities and opportunities for GIT in RIM is founded.

5.2 Road Maintenance Activities and Actors

Road maintenance is a broad term that encompasses a wide range of activities including routine, periodic and rehabilitation. As the focus of this Research falls under periodic activities that are usually prior planned, recurrently budgeted and dependent on several indicators and indices, the actors and activities discussed herein are limited by that scope. Periodic road maintenance is an activity that is undertaken after every 3-5 years within which road defects that are outside routine maintenance are rectified. For efficient and effective execution of periodic maintenance, a proper plan is a prerequisite. Such a plan indicates the state of the road, in terms of maintenance indicators/indices, the scope, cost and the actual activity. The core organisations involved in this maintenance category, together with their roles, are summarized in Table 5-1.

Table 5-1: Summary of Core Stakeholders and Roles in Road Maintenance

Organisation	Role/Activities
MoWT	Its constitutional mandate is to set policy, regulate, set standards, and provide technical guidance and monitoring to the whole of the construction industry. Also, to specifically carry out research and develop local material for the sector
URF	To finance routine and periodic road maintenance activities in the Country
UNRA	To maintain the Country's national roads
District, Urban and Community level Authorities	To maintain the District, Urban and Community Access roads respectively
KCCA	To manage and maintain Kampala city roads
Road Contractors	Implement the actual maintenance works
Road Consultancies	Supervise the implementation of the maintenance works
(MoLG)	Provide support to local government authorities to effect efficient road maintenance

The URF was created by the URF act of 2008. Its main objective as stipulated under sections 6(a),6(b) and 6(c) of the act, is to finance routine and periodic maintenance of public roads and to ensure that public roads are maintained at all times (URF, 2008). The fund is purely for financing road maintenance and does not perform the actual works. It is supposed to be operated as a 'second generation' fund, independent of the government general budgetary system. Sources of the URF are fuel levy, road user charges and any other sources as may be approved by the Parliament of Uganda.

Originally, road maintenance activities were funded using apportioned tax revenues just like the education and health sector activities. Second-generation road funds have moved from that concept and instead, they are funded by certain levies/surcharges designated as 'user charges' and these levies/surcharges were identified separately from general taxation (Price Water House Coopers, 2007). The specific activities of the URF include:

1. To review work plans from agencies,
2. To prepare annual road maintenance work plans, and,
3. To monitor the road network condition while accessing the impact of the money that has been invested.

The UNRA was established by the UNRA Act 2006. Under this Act, UNRA is responsible for the management of the national roads network (UNRA, 2006). UNRA is obliged to manage the improvement/development and maintenance of the national roads network efficiently and effectively besides rendering advisory services to the Government in line with management of national roads. It took over the function of national roads development from its precursor, Road Agency Formation Unit and national roads maintenance that were a responsibility of MoWT (TSDMS, 2011).

KCCA has the mandate under the KCCA Act 2010 to manage city roads (KCCA, 2010). The KCCA engineering department is responsible for design, construction and maintenance of roads within Kampala. It is therefore responsible for collecting data on management of road infrastructure in its jurisdiction.

The mandate of the MoLG is to inspect the performance, provide support, supervise, mentor, monitor, build capacity, co-ordinate and advocate for local governments. There are standards, government policies, laws and regulations and guidelines for local governments that have been set by the line ministries, MoWT in this case. These principles, policies and laws are intended to govern the MoLG during the implementation of their programs. The ministry's basic responsibility is to foresee the compliance of the aforementioned requirements by the local governments.

By virtue of its mission, the UBOS qualifies as one of the 'other' stakeholders in road maintenance. Its primary responsibility is to manage national official statistics. The statistics Act 1998 mandates UBOS to get aggregated data from all ministries, MoWT inclusive. It coordinates producers and users of these data. This it accomplishes by developing a coherent, reliable, efficient and demand driven National Statistical System (NSS). Under the Plan for National Statistical Department (PNSD), UBOS developed a framework for strengthening statistical capacity across the NSS. This is a plan where different stakeholders generate, disseminate and use statistics within the integrated framework. One of the objectives of PNSD is to strengthen national capacity to produce, analyse and use reliable statistics through an integrated NSS and to ensure long term sustainability of the NSS by securing funding for priority data production, analysis and dissemination.

The remarkable use of GIS by UBOS in the management and analysis of its spatial datasets paves way for collaboration with the RIM sector in order to boost GIT use. Additionally, UBOS has contributed to the foundation of GIS in many organisations as the initial source of a number of fundamental datasets. Because of this and it being at the forefront of the on-going **National Spatial Data Infrastructure (NSDI)** initiative in the Country, UBOS is therefore one of the 'other' stakeholders in RIM. The user of the road network, i.e. the public, by virtue of using the infrastructure is a non-core stakeholder. Likewise donors are stakeholders (non-core) in the sense that they directly finance capital road maintenance projects especially through the sub counties (Magidu et al., 2010).

The roles of some of these organisations have been briefly highlighted in Kayondo et al. (2010). However, notice that there are slight changes in both the names and roles discussed. This is because this Research has been on-going since 2008 and several changes in naming and mandates of some organisations have taken effect. Kampala City Council (KCC) for example has since changed name to KCCA. The Ministry of Finance Planning and Economic Development (MFPED) was originally handling the finances of the entire bracket of road maintenance in the Country until 2010; when URF took over to manage finances for routine and periodic maintenance of public roads based on funds generated from road user charges.

The **National Mapping Organisation (NMO)** as the provider of foundation data for mapping is a non-core stakeholder. The use case diagram in Figure 5-1 is a model of the various actors in the road maintenance programs and the conceptual role(s) played by each actor. A use case diagram is a type of the UML behaviour diagram that describes the functionality provided by a system, in this case 'an organisation', in terms of actors, their goals represented as use cases, and any dependencies among those use cases. This diagram is especially important in organizing and modelling behaviour of a system. It is presented at this point to clarify the roles and linkages between participants for RIM in Uganda.

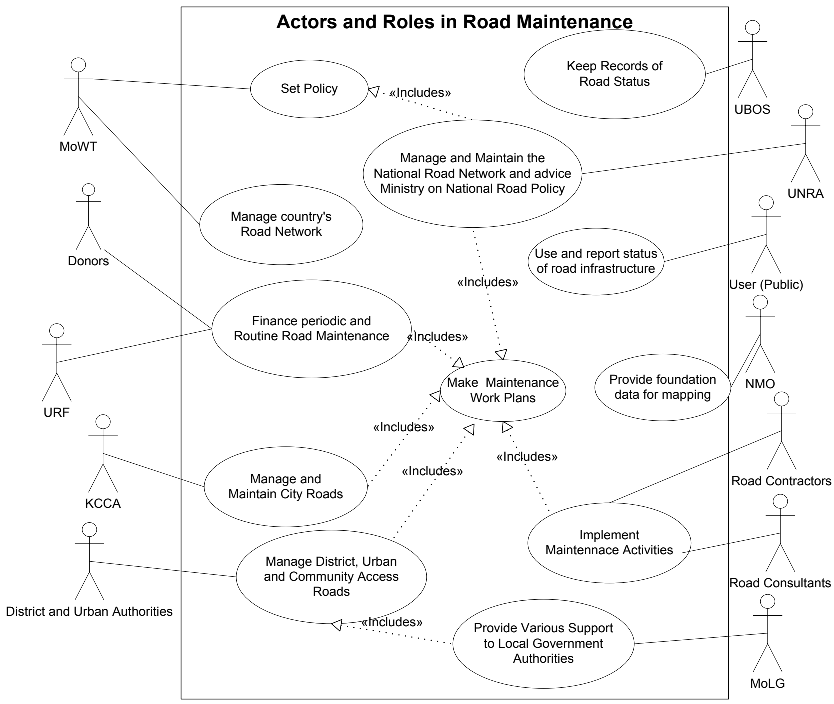

Figure 5-1: Use Case Diagram Showing Stakeholder Roles

This use case model was developed with a background of the business rules outlined below:

1. With advice from UNRA for example, the MoWT is responsible for the development of policy goals and general objectives for the road maintenance sector.
2. The UNRA, District councils, KCCA, Contractors, and Consultants are responsible for the collection and management of records on the condition status of roads. The condition in this case is of two forms - the inventory condition i.e. before specific maintenance has been performed, i.e. the condition that leads to maintenance decisions, and the condition during implementation of maintenance works - as consultants are supervising contractors during implementation. UBOS however collects and manages more national informative statistics of these data for the Government and user.
3. The decision on which roads to include for maintenance is initiated by the UNRA, District agencies, KCCA and the URF. Maintenance plans from each jurisdiction are submitted to URF to secure funding. It is based upon these submitted plans to the URF that a road is included for maintenance in that planning period.
4. Planning and programming of road maintenance activities is tasked to all the core stakeholders. This eliminates UBOS, the donors, NMO and the users. The planning and programming however differs from level to level:

    • The MoWT is responsible for planning the welfare of the roads infrastructure net work at national level,

    • UNRA, District, Urban, & Community councils and KCCA plan for effective management of specific roads in their jurisdiction,

    • Consultants and contractors are mainly concerned with planning for implementa tion after maintenance contracts have been granted to them,

    • The MoLG is responsible for planning and programming of all round development of capacity for district and lower level councils. It is the target ministry expected to enforce the utilisation of GITs in road maintenance by the organisations under its jurisdiction,

    • The URF plans for finances and their equitable use for maintenance of the Coun try's road network.

5. Monitoring and Evaluation is performed at all levels including the public who is the topmost stakeholder as user of the road infrastructure. The public has been found to report incidences of bad roads especially through the media. In some cases this is through riot and in many situations, maintenance of these roads takes place as im mediate action.

These business rules are summarized in Figure 5-2.

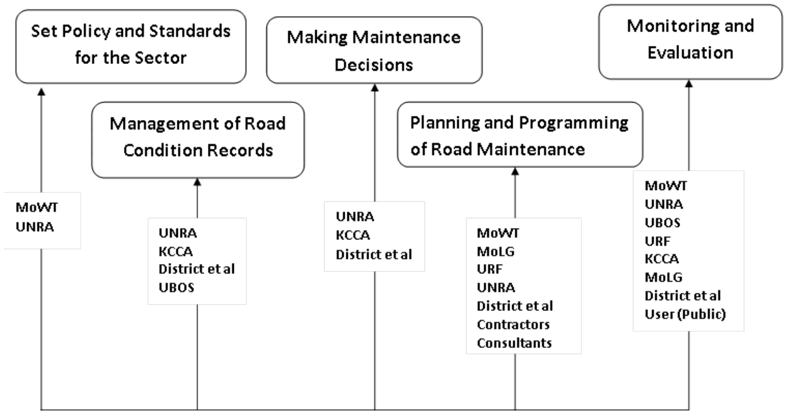

Figure 5-2: Summary of Business Rules Discussed above

Each of the stakeholder organisations has more specific activities performed within their agencies which are not the subject matter for this Research. The delivery and accountability of the end product is also distributed in a top down-hierarchical kind of approach.

- The contractors and consultants are accountable to the agency responsible for the roads for which they have been granted maintenance contracts,
- The UNRA, district agencies, lower level councils and KCCA, are accountable to the URF, MoLG and MoWT. The exact organisation accountable to varies depending on the maintenance task at hand,
- The MoLG accounts to URF and MoWT,
- The URF accounts to the MoWT and finally,
- The MoWT is accountable to the Government of Uganda, through parliament.

This accountability is depicted in Figure 5-3. The directions of the arrows indicate to whom accountability is made.

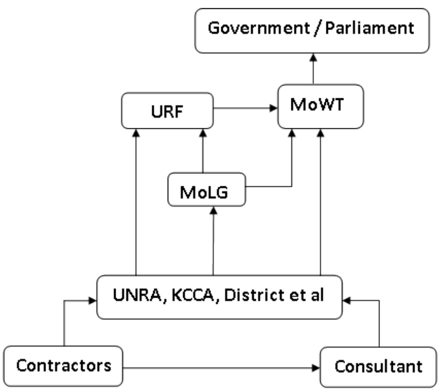

Figure 5-3: Accountability of Stakeholders during Maintenance Decision Making

5.3 Gaps and Limitations of GIT use for RIM

The gaps and limitations to using GIT in RIM have been based on two guiding principles - First (1st), the principle that organisational standalone GIT usage is costly and time wasting hence the SDI concept. The SDI components as presented in Chapter Two were partly used to derive themes for the discussion. The second (2nd) guiding principle, also presented in Chapter Two, the principle of causation, entails, that everything should have a cause and that the cause must precede its effect. The gaps and limitations relationship is therefore a causality relationship where the limitations are the cause and the gaps are the effect. Other themes however emerged directly from interactions between participants and the review of documents and reports from the RIM sector. Content under the identified themes was derived from qualitative data analysis, including categorization, interpretation, abstraction, and integration of findings from interviews, FGD, observations and field measurements. This content was backed by the requisites of SDIs as discussed in Chapter Two. The performed GIS analyses likewise formed a part of the content under some themes and in other instances constituted independent themes.

A summary of the identified gaps and limitations is presented in Table 5-2. The limitations involve those matters that are hindering attempts to further GIT use in the sector.

Table 5-2: Gaps and Limitations Summaris

Gaps
Inadequate involvement of GIT in the works of the road maintenance organisations
Inappropriate institutional arrangements and partnerships
No sharing and collaboration with regard to data
Lack of a **Spatial Data Infrastructure (SDI)** for RIM
Limitations
Absence of sufficient policy components
Budget limitations coupled with unconventional maintenance plans
Absence of standards for geographic datasets
Inadequate geospatial capacity in organisations
GIT digital divide in perception, adoption and affordability among stakeholders
Variations in location referencing approaches

5.3.1 Institutional or Organisational Gaps and Limitations

Over all, when addressing GIT in RIM, emphasis has been placed on technical issues at the expense of institutional and data-related ones. The technical issues can be exemplified as the focus of organisations on system developments. The UNRA's road and bridge management system and the RAMPS for the District Urban and Community Access roads are clear indications of such technical emphasis of GIT initiatives in the sector. Notice that system functionalities are based on data and geospatial capacity for example. If data related concerns like structures, semantics and terminologies, and geospatial capacities of the personnel manning them are not addressed, these initiatives may not be successful. As earlier mentioned in Chapters One and Three, the sector's immediate need is not systems but the institutional relationships that facilitate data sharing and collaboration, enhancement of geospatial capacity, financing and policy enactment, all on which the success of systems are built. In contrast, the gaps and limitations discovered from this Research are more inclined to institutional challenges, and partly data related constraints than technical aspects. This inclination is also realized by some scholars for example Somers (1994); Ralphs and Wyatt (1998); Obermeyer and Pinto (1994); Campbell and Masser (1995); Ramasubramanian (1999); and Clodoveu, 2005.

The focus of GIT implementation projects on the technical as opposed to institutional and data related concerns dates back to almost 20 years ago, in the early years of GIS. This is perceived from Somers (1994) who then claimed that it was only within the past few years that attention had shifted from the technical aspects of GIS implementation to the organisational ones. Ralphs and Wyatt (1998) also emphasized that the focus on technical rather than institutional and data-related issues was one of the common problems that GIS applications encountered. Similarly, Obermeyer and Pinto (1994), Campbell and Masser (1995), and Ramasubramanian (1999) remark that all but the most naive users will acknowledge that successes and failures of GIS implementation are influenced by a wide range of factors that have little or nothing to do with technical considerations. Clodoveu (2005) concludes considerations from the development of a LSDI in Brazil with an appraisal on the importance of organisational issues in information management. Unfortunately, these concerns are still neglected even today in the RIM sector. The institutional issues as evolved from this Research take the form of policy enactments, data sharing and collaboration, geospatial human resource capacity and financial concerns.

This is not to conclude that the Research focused on establishing only institutional related gaps and limitations. Both sources were devoted equal attention during investigation and in the discussion to follow, it is noted that both technical and organisational gaps and limitations are affecting the foundation of GITs in the RIM sector. It is only obvious that the institutional concerns are more dominant for this Study. For purposes of a well-rounded discussion on the evolved gaps and limitations, the two categories, institutional and technical, have not been singled out individually but each played up as and when their concerns arise.

5.3.2 Inadequate Involvement of GITs in Organisational Activities

GITs are not integrated into the working procedures of any of the involved organisations. It is observed that GIT usage is on project basis and convenience. A few cases can be pinpointed. The KCCA formerly KCC, was involved in a capacity development project at the start of 2003. Under this project, GIS shapefiles for roads in Kampala were collected and managed within a GIS. Almost 10 years now, the GIS datasets for Kampala city, present at KCCA, that are well represented both in terms geometry and topology, are the datasets that were left behind at the end of that project. The additional datasets that have been collected under the authority lack topology. Their use is limited to Computer Aided Designs (CAD) as they have been developed for graphical display with no feature coding. Figure 5-4 is a map of these CAD drawing of the roads in Kampala jurisdiction.

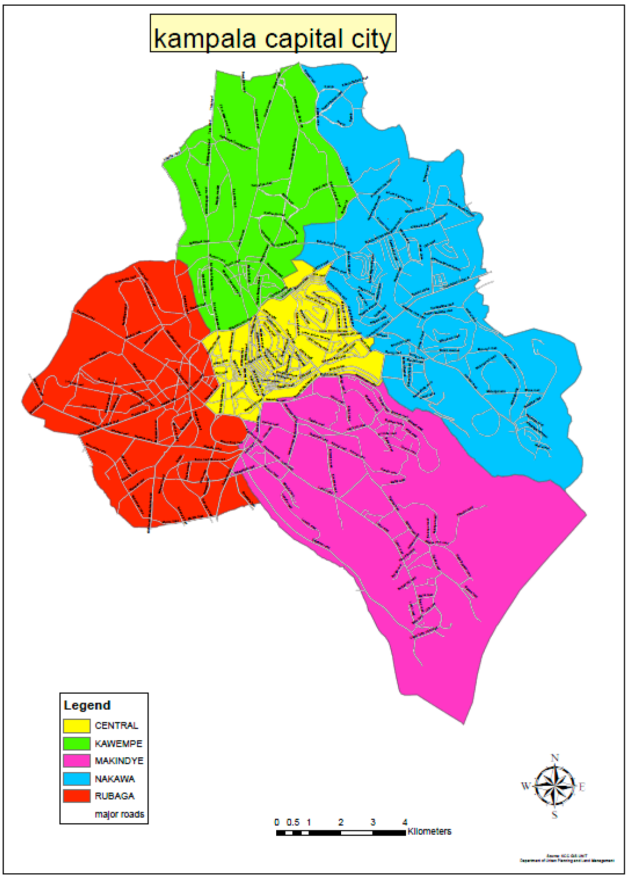

Figure 5-4: A Roads Map of KCCA
Source: KCCA GIS Unit

Besides being used at project basis, the use of satellite imagery in the sector was also witnessed with only 3/23 organisations that participated in the Study. These companies are COWI, Norplan and PROME. This opportunity to use the imagery was under the specifications for the tasks of the jobs that these companies were undertaking at that time. In such a case, the methods of data collection and management were clearly outlined in the project requirements. Also, the images were usually provided as they were procured with project funds. Likewise, the required software for image processing was provided. Unfortunately, this opportunity ceases at the end of the project. Hardly any attempts are being made to continue using the technology for even other applications within these organisations at the end of the project. One organisation, Norplan, showed interest in developing an understanding of the benefits of using imagery to update spatial datasets. For lack of funds to procure imagery, this organisation is using Google Earth for this initiative. This is seen as an effort to further GIT use in the sector.

During this Research, there was a consultancy, 'Road Inventory Study' which is in its later stages today. Its principal objective was to assist UNRA to establish a national roads databank and asset management system. These two deliverables are to be used as decision support tools for annual and multi-annual maintenance and investment work plans and for reporting on national road and bridges in the Country (UNRA, 2007). The future sustainability of the system is fundamental as depicted in the project's terms of reference and the strategies by the consultant during the assignment are therefore directed at this objective. For example, training of the client's staff- UNRA staff, and technology transfer is paramount and accordingly being executed. It is hoped that the developed system will be sustainable.

Majority of the consultants and a few contractors use the Computer Aided Design or Computer Aided Drafting (CAD) software for drawing and communication of their works. The mention of GIS triggers the need for differentiating between it and their traditional AutoCAD. The argument that AutoCAD models objects in the real world, while GIS models the real world itself, was not easy to go with. AutoCAD and AutoCivil are predominantly used. AutoCAD is a CAD software application for 2D and 3D design and drafting of real world objects. It is used by architects, engineers, drafters, artists, and others to create precision drawings or technical illustrations. AutoCivil on the other hand is a comprehensive civil engineering software package which runs within AutoCAD. It performs surveying, mapping and roadway designs among other applications. Both packages have a coordinate reference system, can describe and process graphics data, and can also handle attribute data, although they are limited in conducting geographical analyses. Notably though is that accessibility for geospatial context of designs requires integration of CAD into GIS. Attempts of ensuring this are on course in various researches but this is not the subject of discussion here.

In order to continually build capacity and infrastructure in GITs, it is in order that their use is incorporated in the on-going practices of organisations. In the long run, sustainability of GIT usage will be derived from their frequent use for planning, reporting and decision making of the routine and periodic maintenance activities. One district engineer was quick to mention that his jurisdiction is so small that one could just drive through to establish maintenance needs. The engineer's argument was that the geospatial technologies advocated for are applicable for 'bigger' organisations like the UNRA and the MoWT. This mentality of top organisational managers is a stumbling block to GIT initiatives in the sector and should be discouraged.

5.3.3 Inappropriate Institutional Arrangements and Partnerships

The current institutional arrangements are not inclined to developing and maintaining lasting partnerships, standardized data and a coordinated GIS infrastructure. An instance in reality is the existence of consultancy companies for example consultant X which has housed projects where GIS has been used for transportation applications.

On projects where consultant X is the consultant supervising contractor Y, it is good practice to introduce the concept of using GIS to manage datasets, data structuring, analyses and reporting. Instead, consultant X adapts to the manual methods of data structuring, analysis and reporting that are traditionally employed in these construction companies. Notice that the data themes for road maintenance are predominantly the same for all jurisdictions. In reality though, in executing their supervisory role, consultant X should be in position to introduce contractor Y to the benefits of exploring GIS for data management and reporting. This however is to the disadvantage of the technology that would otherwise have advanced within the sector if introduced to contractor Y.

Another case in point is, on implementation of maintenance tasks, in one project the contractor may report to the consultant who reports to the accounting agency e.g. UNRA, which accounts to the URF. The URF finally may have to report to the MoWT. Usually, the reporting and accounting workflow is organized for a particular project on an ad-hoc basis. In cases where the same consultant and contractor have to work together on another road maintenance project, a different institutional arrangement is always defined basing on the accounting agency which may be a district office this time. Once processes and institutional arrangements change as a result of changes in project reporting, the data format and standards will also automatically change. Considering that these involved organisations use similar datasets in resolving the routine and periodic maintenance problems, it should be a requirement that, 1, these datasets are of standardized formats and that, 2, formal arrangements/partnerships are made between organisations involved in RIM. This should be in such a way that standard forms of reports used by organisations are drafted and approved. It should then be these forms and reports used for communicating within the organisations. The lack of this formal arrangement and standardization of dataset structure has made it quite difficult to archive these data in a coordinated GIS infrastructure for RIM.

By the nature of the routine and periodic activities involved in road maintenance, the organisations involved are envisaged to have an arrangement or partnership to ease decision making through for example, the avoidance of multiple collections of similar datasets, harmonised reporting mechanisms and execution of works. This arrangement should for example take care of the structure of the common datasets in use, the reporting methods by implementing agencies, formats for the annual work plans, accountability formats to the financing agencies, etc. This identified gap in the RIM sector of Uganda was also earmarked by Rajabifard and Williamson (2001b). "Inappropriate institutional arrangements are often the biggest limitation in undertaking sharing spatial data to facilitate regional as well as global cooperation" (Rajabifard and Williamson, 2001b, p.23). The inappropriate institutional arrangements and partnerships are central and related to the next gap to be discussed, i.e. lack of data sharing and collaboration. This is also evident from the previous quote of Rajabifard and Williamson (2001b) above. However, for purposes of coming out clearly on the technical aspects related to data sharing requirements, the two have been presented as separate gaps.

5.3.4 Lack of Sharing and Collaboration with Regard to Data

Data sharing and collaboration is vital in avoiding duplication of efforts for the organisations involved in RIM. Duplication of efforts involves both wastage of resources and exploitation of man power. All GIS projects irrespective of the application at hand require some common datasets. These datasets have a variety of names but all carry the same meaning. The names range from fundamental, core, base, to framework datasets. The purpose of these datasets is to give the map meaning in form of a background. This fundamental data is the same as that used by the utility management systems for example, water, power, telephone lines, and land use. However, there is lack of collaboration between agencies in the road maintenance sector and the utility companies, especially with regard to sharing data. Majority of the utility companies National Water and Sewage Corporation (NWSC), Uganda Electricity Distribution Company Limited (UEDCL), UMEME Limited - the private company responsible for management of electricity supply in the Country for example have established GIS units through which collaboration would benefit the RIM sector and further the establishment of its GIT initiatives. Lack of data sharing hinders the development and utilization of the full potential of GITs. For example, GAO (2003) contends that long standing challenges to data sharing and integration need to be addressed before the benefits of GIS can be fully realized.

For the project on establishing a national roads databank and a road management system for UNRA, the intention is to have a web based application by uploading the data on an ArcGIS server. This data is to be collected at regularly defined intervals to ensure it's up datedness. This will be a beneficial step towards data sharing in the sector.

From the FGD, interviews and observations, the limitations (read 'Causes' from the principle of causality), leading to this absence of data sharing and collaboration are documented in the following subsections. Note however that some of the underlying problems although leading to a social institutional gap, accrue from technical factors relating to spatial data and its management.

(A) Insufficient Awareness of the Existence of Pertinent Data in other Organisations

This has resulted in two circumstances. 1. Islands of unexplored data that are utilised for individualist purposes, and 2, independent organisations duplicating efforts by remapping of the road infrastructure. The National Forest Authority (NFA) has core data on the land cover types of Uganda. Under the national biomass assessment project that was intended to give an account of the biomass production in the Country, NFA, the organisation tagged with this responsibility accumulated all relevant geographical datasets that were needed to undertake the task. A representative national road network was among these datasets and today, it forms a part of the source core datasets used by all spatial data users. Some organisations like the MoWT and UBOS have since then managed to update this NFA dataset that was originally generated in the 90's. As already foregrounded, in its mandate to maintain the statistical database of the Country's assets and resources, the UBOS is in custody of some GIS datasets of the road infrastructure as part of the Country's assets. Likewise, the various utility companies, NWSC, UMEME, and UETCL also have GIS datasets for their various jurisdictions. Note that as earlier cited, there are fundamental datasets that are required for all GIS projects which are shareable content amongst the technology utilizing groups prior defined. This data sharing is however not forthcoming as there is insufficient awareness of the existence of this data among the RIM stakeholders.

(B) Lack of Metadata

Lack of metadata is the prime barrier to geospatial data sharing amongst organisations using GIS. Metadata is sufficient documentation about the geographic datasets, data about data content that helps the user to discover data and access its usefulness for the task ahead. It includes aspects such as;

- Means of creation of the data,
- Purpose of the data,
- Time and date of creation,
- Creator or author of data, and
- Standards used. All these being vital for one to make use of a dataset in question.

All the datasets used for this study lack metadata. Besides being a major requirement for GIS datasets and data exchange, the lack of metadata has created uncertainly in data quality and this is affecting data exchange and collaboration between organisations in the sector. Some organisations have for example registered their un-readiness to utilize data that has no metadata.

Three vertical levels of metadata are identified by the Spatial Data Infrastructure Cookbook (Nebert, 2004). The concept of metadata discovery is fundamental in ascertaining the availability and semantics of spatial data for effective data sharing. This is the coarsest level of metadata that is primarily used for discovering spatial data. It is this type of metadata that will avail an awareness of the existence of specific datasets in defined organisations. Exploration metadata is that level that assists the user in evaluating the fitness for use of various datasets when set to solve specific problems. Exploitation metadata is the most detailed of the 3 levels and it includes details of data dictionary, data schema, projection and geometric characteristics and other useful parameters for the proper use of geospatial data.

(C) Differences and Uncertainties in Reference Frames

Some organisations have datasets with no spatial reference. Figure 5-5 is a pop up window from exploration of the source data elements of one of the road datasets in the custody of a private consultancy firm.

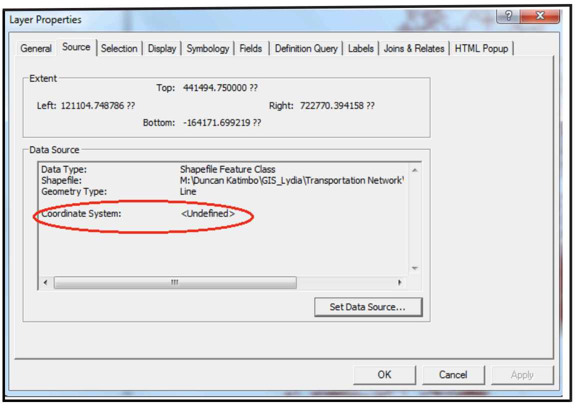

Figure 5-5: Roads Dataset with an Undefined Coordinate System
Source: Duncan Katimbo

The window shows that the dataset in question has an undefined coordinate system. This basically means that it is only possible to visualise this dataset. Put differently, if datasets with and without defined coordinate systems are to be used in combination, only visualisation will be sufficient for their combined use. Having the same datasets in a CAD environment for example will play the same role. On analysis of the collected roads datasets from the sector, the mostly used datum, the framework within which location is specified, is the **World Geodetic Spheroid 1984 (WGS-84)** with custom defined **Universal Transverse Mercator (UTM)** UTM_Zone_36N coordinate systems. This is because the data has been collected from GPS devices and the most recent spatial data such as satellite images and GPS observations are based on WGS-84 datum. In effect, the WGS-84 datum is for the moment used by UNRA, PROME, UBOS, and District roads authorities using RAMPS.

Preference of the WGS-84 datum is also attributed to the limitations of the UTM coordinate system which is the standard as set by the NMO of the Country, i.e. the Department of Lands and Surveys. The UTM is a worldwide projection which divides the world into 60 zones each of 6 degrees of longitude. The numbering increases eastwards with zone 1 running from 180^0W to 174^0W line of longitude. Uganda lies in 2 zones, UTM zones 35 and 36 and because of the position of the equator, it has coordinates in the north and south hence (UTM Zone 35N, UTM Zone 35S, UTM Zone 36N, and UTM Zone 36S). This literally means that areas south of the equator will have negative coordinates. Organisations solve this problem in different ways, often by defining false origins, which in many cases creates issues of inconsistency. The department of Lands and Survey is however having plans to adopt WGS-84 as the national standard datum (Okia, 2007 as cited by Musinguzi et al., 2007). This is envisaged to ease the conversion concerns related to the Arc 1960.

(D) Data quality aspects

Some of the GIS datasets owned by organisations have questionable integrity which ranges from the positional accuracy, logical consistency, attribute accuracy, to completeness. For example, an overlay of 2 datasets indicates a mismatch between the roads network at larger scales. Figure 5-6 (a), (b) and (c) are overlay maps of two datasets from PROME and UBOS. At the scale of 1:150,000 the road centreline matches for the two datasets.

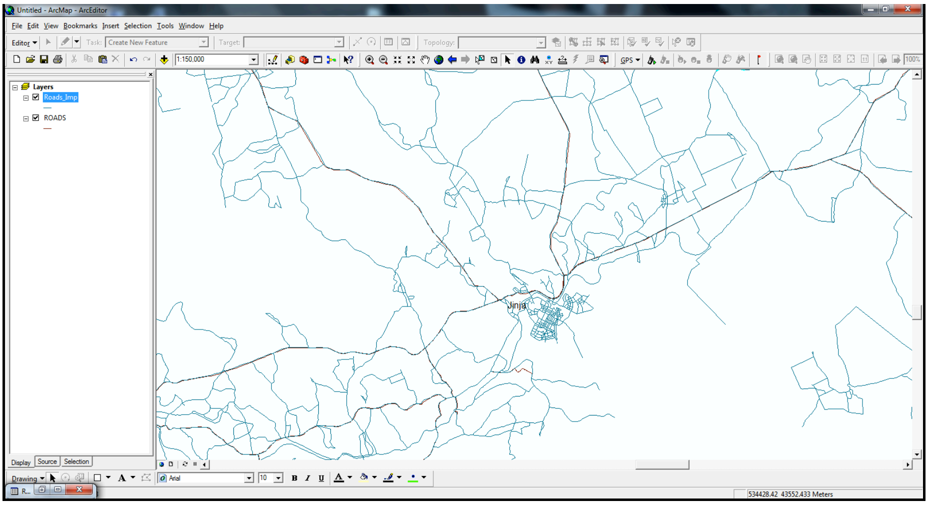

Figure 5-6 (a): An Overlay of Datasets at 1: 150,000

However, at a larger scale of 1:50,000, the mismatch between the two datasets is more exaggerated. Beyond this scale (see Figure 5-6 (c), the mismatch becomes unreasonable for analysis of combined datasets to yield meaningful results. This mismatch however varies between sections of the roads at different scales.

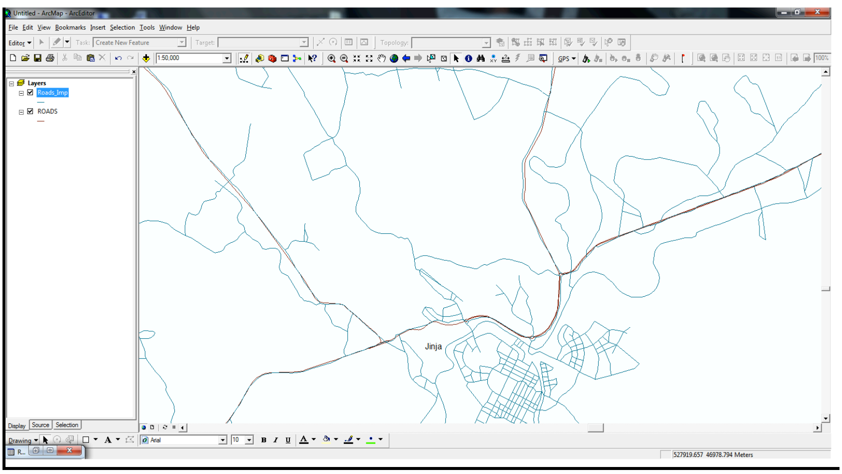

Figure 5-6 (b): An Overlay of Datasets at scale 1: 50,000

The explanation for these differences in data qualities is variations in the methods of network compilation, i.e. techniques for data collection, including both equipment and personnel. This also questions the geometry of the road in the compared datasets. When datasets of the same theme do not spatially overlay, analyses on them becomes inefficient and subjective hence a limitation to decisions made. This questions the positional accuracy of the datasets. This is also a hindrance to data sharing and collaboration in the sector.

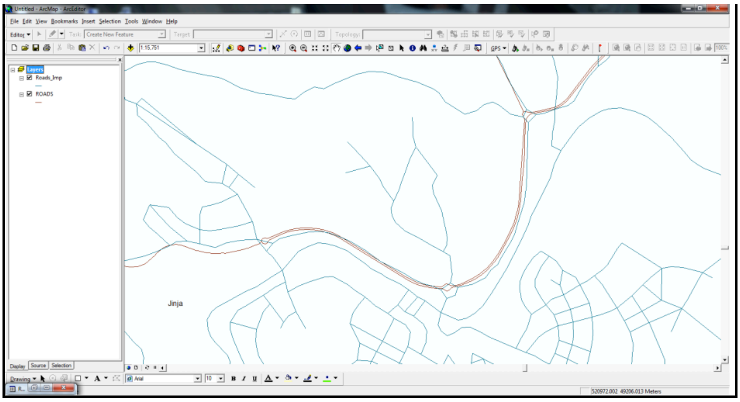

Figure 5-6 (c): An Overlay of Datasets at Scale 1: 15,000

Additionally, the GPS data collected for several projects to-date does not match well with the data archived by the NMO, the Department of Lands and Surveys. There have been tremendous improvements in the GPS equipment offering better accuracy results. In effect, the foundation data provided by the department, which was established as early as the 1960's, is of a lesser accuracy. This explains the non-matching data provided as control for independent project level mappings. Also, the maps archived at the surveys and mapping department are for urban areas. The Country has tremendously advanced and new roads are set up with others being planned. In consequence, for each new project undertaking, a new topographic map should be prepared. Otherwise, the quality of the existing map is questionable.

(E) Data pricing irregularities

Although some organisations like UBOS freely share their GIS datasets with stakeholders in the sector, it is noted that the pricing is not uniform across organisations that sell their datasets. Besides the un-uniformity, the price in other cases is also quite exorbitant. The price of data is not prior stated and as a result, data is bargained for as if in a market place. An organisation or personnel with limited bargaining skills would either buy data at an unfair bargain or not buy at all. This will in effect be a disadvantage to the sector as some organisations that cannot afford data will in the long run decline the sector in advancing with the use of GITs as decision support tools. This irregularity in the pricing of GIS data has been noted to affect data sharing. Where data cannot be freely availed, the price should be affordable in context of the Country's economy. Consultants and contractors have been heavily affected by the price fluctuations in geospatial datasets. This is because they claim to have limited revenue as compared to the government organisations like the MoWT and UNRA who often utilize donor funds and make use of tax revenue from the nation. Mapping organisations, the sources of some fundamental datasets, e.g. National Environmental Management Authority (NEMA) and National Forest Authority (NFA) have at least set up prices for existing geospatial datasets. Otherwise, in many circumstances, depending on the working relationships between personnel and their respective organisations, the price will depend on negotiation skills. Even though Kalande and Ondulo (2006) bothered to recommend a combination of pricing mechanisms for geospatial datasets established by a number of institutions in East Africa, there is no central pricing policy in existence as yet.

(F) Copyright and privacy policies

There are no copyright and privacy policies governing data sharing in the sector. A consultancy company participating in this Study has gathered some GIS datasets from their various road projects for which they find it difficult to share. For instance, they have highlighted a situation where a researcher obtained their data only to find it wrongly referenced in the researcher's publication. This has created some form of resistance from this category of stakeholders for two reasons:

1. Poor image of the organisation by wrongly publishing its datasets, and,
2. Some researchers were obtaining payment for the research for which organisational data was freely availed.

The organisations from which this complaint was obtained felt that this payment could form part of their revenue as well.

Another cited fear was to do with having the same datasets get back to contracting agencies by consultants who will have been contracted to perform excerpts of similar works in future. For the complaining organisation, sharing of datasets creates an impression that a few manipulations by another consultant would provide the same datasets when another task is contracted to them. All these concerns are weighty and cannot be blamed on the individual organisations but the policy enforcers who need to provide some form of security to organisations so as to enforce data sharing and collaboration. The laxity in copyright and privacy policies has created a monopoly of GIS datasets from departments and this in the long run has maintained these organisation's strength and reason to exist.

(G) Technological issues related to incompatibility of software platforms

There are differences in GIS software packages in use by the organisations that have GIS systems. Issues of data interoperability come into play when datasets created in given software are to be manipulated within a different software package. This has in effect caused a one man's dataset scenario and hence dominance of datasets by some organisations. The most common software used are ArcGIS and ArcView from ESRI, and ILWIS from the International Institute of Earth Sciences and Observations (ITC). ITC has trained a number of professionals in GIS related courses for various application domains. With them return the ILWIS GIS software that they use at individual level. This software is however now on the public domain as open source. Commercially, ArcGIS and ArcView are the most used software. A few organisations make use of Intergraph's Geomedia, IDRISI and Erdas Imagine software packages.

(H) Lack of efficient telecommunication infrastructures

Efficient data sharing requires efficient telecommunication infrastructures. Presently, access to geographic data through the internet is limited as high connection cost and low bandwidth restrict data sharing. The efforts of physical movements between offices are claimed to waste time that would otherwise be used for other duties.

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. For many of the successful technological inventions, benchmarking of best practices is achieved through collaborations as skills and capacity are strengthened in the process. Interviewees have affirmed that the society in the RIM sector of Uganda is a poor one which rarely works together to build each other's capacity. There is a willingness to share data and collaborate with fellow contractors for instance, but the competition for road contracts limits the initiative. This is attributed to the poor society prior mentioned. An anonymous contractor confirms that it is not fair to build skills with a collegiate contractor for fear of competition for the same maintenance contract in the future.

5.3.5 Lack of a SDI for Road Maintenance

There is no SDI to facilitate decision making in the sector. The components of the SDI should include policies, data, people, access networks and standards. Even though the draft national ICT policy of May 2002 recognizes the relevance of ICT in national development, this policy is yet to recognize GI and the associated technologies as components of ICT. In consequence, there are no policies on which the sector finds security in advancing the use of GITs considering the large amounts of money involved in kick starting such systems. The availability of high quality fundamental datasets is questionable due to the lack of metadata. Also, the capacity of the personnel working with geographic datasets is inadequate. Each organisation collects their own datasets and without uniform standards, the use of these data by sister organisations often faces interoperability challenges. In consequence, such organisations operate with their own datasets without consultations with others within the sector. Initiatives for establishing a SDI - a framework for connecting all users of GI to the producers or data through an efficient infrastructure (Nebert, 2004) are not forthcoming in Uganda. This frustrated effort is one of reasons that the RIM sector has no database to address fundamental sectorial road maintenance requirements. 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 organisations of geospatial data in Washington. 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 essentially because district roads link to national roads. This same data is useful to road contractors and consultants in monitoring and reporting the implementation works on road maintenance projects. However, the use of these data for all organisations with a role in road maintenance is only possible if the data and procedures for use meet a set of basic and consistent guidelines and protocols. For this to materialize, the existence of policies and standards governing data collection and management is paramount. This whole described framework encompasses a SDI for RIM.

A number of organisations and communities are seeking to establish standards for GIS. But because these organisations have different scopes of establishing these standards, each concentrates on a particular aspect of GIS. Therefore, presently there is no standard for GIS-T available which encompasses all requirements for road maintenance data. Issues of topology, linear referencing systems, and graphical representation of road segments are still being tackled in different standards. In effect, none of the developed standards to-date can be solely applied to GIS-T datasets (Demirel, 2002). Some of the existing data standards in the transportation field are Geographic Data files (GDF) (GDF, 1995; 1999) particular to object models, **National Cooperative Highway Research Program (NCHRP)** 20-27 particular to linear referencing (Opiela, 1997; Vonderohe et al., 1998; and Scarponcini, 2002) and the Topologically Integrated Geographic Encoding and Referencing (TIGER) that is particular to network models in the USA. Object models are those that endeavour to identify transportation entities as objects. They aim at describing road and road related data. Network models are those concerned with the topology of connections and intersections of nodes and arcs of a transportation system.

The GDF standard was developed as a draft submitted to the European committee for standardization. It is a feature-based geographical data standard (Arctur et al., 1998) widely used in the ITS industry. A consortium of public and private entities developed GDF to improve the efficiency of capture, production, and handling of road related geographic information (Curtin et al., 2003). The NCHRP in USA is designed to facilitate research to develop practical solutions to problems facing transportation agencies (Vonderohe et al., 1998 and Adams et al., 2001) in establishing foundation for location referencing. The TIGER files are a network structure for applications of GIS in transportation. These files provide national coverage of the transportation network and other features for spatial data users in the USA.

Presently, the NSDI inaugural in the Country has made a recommendation to 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.

5.3.6 No Policy Component for GIT Use

The absence of a policy component under the draft ICT policy, which would encourage the use of GITs in RIM and set forth the abiding standards, is a limitation to the sector. The overall policy addressed in this section encompasses the whole body of the previously mentioned pricing, copyright, and general GIT emphasis in RIM. One of the principal inputs for effective management is well defined objectives such as would be stated in a policy framework and appropriate and up-to-date information to support management decisions (Paterson and Scullion, 1990 and Robinson et al., 1998). A policy is a principle or rule to guide decisions in order to achieve rational outcomes. A GIT Policy component should be able to provide guidelines of use and set forth principles that govern use of the set technology. 100% of the road contractors in this Study for instance argue that they have no reason to invest in GIT applications if their use has not been set as mandatory. The absence of a policy statement governing custody and use of spatial data in the sector is the backbone to the gaps and limitations facing the usage of GITs for road maintenance. Moreover, this policy component absence seizure affects not only the road maintenance division but also several spatial data using departments throughout the Country like the utility companies prior mentioned. This takes us back to formalized arrangement and data sharing constraints that have also been limited by policy directives.

The draft national ICT policy framework for Uganda of May 2002 recognizes that ICT plays a big role in the stimulation of national development and globalization of the economy. Besides existing as a draft, this ICT policy does not yet recognize the role of GI. Currently, the use of GIS in Uganda can be characterized 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, which have enacted Acts for SDI development. These countries have gone steps ahead in developing policies for the management and utilization of GI. Other countries and directives 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 lessons especially in order to develop its NSDI, an infrastructure that will eventually boost the development of GIT usage in all relevant sectors in the Country.

Within the MoWT, there is an on-going initiative to establish a **Transport Sector Data Management System (TSDMS)**. The consultant's report (TSDMS, 2011) on this initiative has been analysed for this Research. A lot of data manipulation is involved in executing the ministry's obligations. In broader terms, these obligations include the provision of safe, efficient and reliable transport services in the Country, and setting standards, policies and regulations to govern the transport industry. Additionally, the ministry carries out strategic planning and establishes and maintains the necessary infrastructure at a national level. Currently, the relevant data is scattered within the various departments. The ministry realizes the high costs involved and the difficulty in compiling harmonized information from departmental standalone databases for its Transport Sector Statistical Plan (TSSP). Today, consultancy services have been procured to address the aggregation of this data into a centralized TSDMS to assist in strengthening the MoWT, to effectively execute its new policy, regulatory and monitoring functions. This involves putting in place adequate procedures and resources to facilitate collection, processing, analysis, storage and dissemination procedures for handling this data. The consultant appreciates the role of GIS Technology in the integration of the datasets and goes ahead to propose it as the frame work for their task. It is only hopeful that the proposal matures as this initiative is envisaged to spear head the use of GITs in all road applications in the ministry.

Otherwise, today, there are no defined policies on sharing of spatial data among the institutions involved in this Study. The data custodians use their discretion to assess with whom to freely share or charge a fee for a particular dataset. Issues relating to user rights and obligations, user agreements, liability, pricing, and data distribution and redistribution are quite abstract to the responsible data custodians. In fact some of the datasets used for this analysis were acquired over a cup of tea! The issue of data sharing often raises questions of intellectual property. This is because spatial datasets are expensive to create and are now very easy to copy. Appropriate intellectual property rights are necessary for spatial data as signalised by Rajabifard and Williamson (2001b).

5.3.7 Budget Limitations coupled with unconventional maintenance plans

Insufficient funds to enforce the use of GITs have been reported in the sector. In Uganda, it has been the tradition that budgets and programs for road maintenance works be prepared on a historical basis. This implies that each year's budget is based upon the amount disbursed from the previous year with an adjustment to provide for inflation, interest rates, and foreign exchange rates among others. This is coupled with the availability of funds as the number one determinant.

The procedure of funding as reported from the district and municipality engineers in charge of road maintenance follows two scenarios that are each in two stages.

Scenario A:

1. The URF communicates the sum of money available for road maintenance to specific jurisdictions for that financial year,
2. Maintenance plans by the responsible agencies are then prepared based on the communicated funds.

Scenario B:

1. The URF calls for maintenance plans including budgets from the various road agencies,
2. Basing on the submitted plans and budgets and the availability of funds for that particular year, the URF provides for the maintenance requirements accordingly.

In both scenarios, the plans being assessed have only basic records indicating the condition of the target roads. Justification for inclusion of roads in the budget is based on the importance of the road and its average condition over uniform sections. The norm has been focused on funding based on availability. Often times the available funds are not sufficient to finance the underrated road maintenance requirements. Whereas some agencies will make use of the advanced funds productively, they may not be able to exhaust the targeted works. This is because the maintenance plan is never dependent on exhaustive road condition. However, it is a requirement that budgets be prepared basing on objective needs-based approaches to incorporate knowledge of the condition, structure, and capacity of the roads being managed. This Study attributes the question of agencies returning huge sums to money to the treasury as reported through media (Musinguzi, 2011) to the lack of a proper maintenance plan and the highlighted funding procedures. A case in point is poor budgeting or the lack of it which is dominated by basing budgets on previous year's expenditure. Once maintenance plans are based on subjective road condition updates, funds availed based on them are likely to be insufficient. The root cause of poor maintenance plans is the absence of adequate decision support tools for assessing and planning maintenance works. If proper systems coupled with the right data were available within these organisations, plans on which allocations are made would be prepared with knowledge based inputs. In effect, accountability would never be an issue as maintenance programs will be executed following data founded methodologies. Otherwise, failure to account often creates confusion to the public which imagines that there is a lot of redundant money in the sector which is not the case. The funds required to maintain roads in condition are actually not sufficient.

The GIS project at KCC in 2003, whose intention was to build GIS capacity within the council, is still referred to today. This was because of its untimely ending that caused no benefit realisation simply due to budgetary limitations. At the end of the project, there were no funds to continue with data collection so as to keep updating the GIS that had been set up. An existing budget on project sustainability would have saved the situation of a collapsing project. Unfortunately, budget allocations are equally not readily available! Also, RAMPS is reported to be ill functioning as its progressive development was hampered by limited resources and unqualified staff, among other requirements to run the system.

Funds are one of the major requirements to accelerate the initiation of GIT projects in any organisation. Even though the operational costs are manageable, the initial capital for GIS establishment is quite high. Besides the costs for equipment and data collection for GIT initiatives, building GIT capacity and infrastructure also require a predefined budget. By building capacity is meant the establishment of training programs for personnel to effect data collection and management. GIT infrastructure on the other hand is that framework of computers, systems, and software to facilitate works. Like any other technology, GIT usage requires continuous measures of improving capacity to handle the fast growing technology. Periodic training of the organisation's professionals in GIT undertakings involves instilling potentialities for adapting to newly developed software, interoperability of these software platforms, improved analyses of GIS data, etc. This too requires funds. Even though much of the satellite imagery is freely available today, the images face a challenge of being old. The up to date imagery is quite costly to be procured by the organisations. Budgeting of funds for such settings is a requirement. It was clear in the minds of all the contractors interacted with that their revenue is not worth the investment in these technologies. Overall, there are widespread concerns with funding constraints for GIT initiatives to take foot in the sector. This absence of funds to proceed with the required activities has globally contributed to undermining durability of GIT based projects in the Country.

5.3.8 Absence of Standards for Geographic Datasets

The structure of data, also referred to as syntax, their formats and terminology are quite different amongst organisations. This is a purely technical dimension of GIT gaps that concerns data and its attributes. The data syntax, format, semantics and terminology demonstrate its content and standard and quality in the long run. However, these frameworks that should be ubiquitously acceptable, at least for a sector dealing with similar datasets, do not exist. This coincides with the National Academy of Sciences (2002) and Hancock and Fletcher (2004) that there is no universally accepted framework for geographic data management in Africa. Likewise, there is no infrastructure to support the use of geographic datasets in Uganda. Each organisation produces data to their own standard.

Decision making for road maintenance requires access of data from multiple sources. To this effect, organisations using similar datasets should be in a position to effectively share these data when needed. Sharing and effective use of GI requires that the data are collected to a standard, maintained and updated on a regular basis. The support infrastructure to enforce this is however lacking in the road maintenance sector. The dataset syntax/structures, formats, semantics and terminologies differ amongst organisations.

To assess semantics and terminology of datasets, a comparison of the meanings of the terms used in the various GIS databases was made. This is a prerequisite for establishing data sharing frameworks between different organisations. The terminology used in the databases analysed is disordered and not uniform. For instance, surface type in one database is sub typed into paved and unpaved. In another database, the terms sealed and unsealed are used. In some circumstances, the two terms are used in the same database hence creating confusion on the difference between the two. A paved road is one that is sealed and vice versa for an unpaved road. Figure 5-7 is an example of the database where the terms, 'surface', 'pavement', 'sealed' and 'unsealed' are used confusedly. In other databases, the terms 'pavement', 'surface', 'carriage way' and 'road' are used synonymously to mean the road way on which cars traverse.

Attributes of sections_0305

FID	Shape *	EASYREFNO	FIRST_SECT	LENGTH	ADT	PAV_'RI	UNP_IRI	SURF_TYPE	PAVE_TYPE	CWAY_WIDTH	SHO_WIDTH	LANES	CLASS_TYPE	SURCLSS_TY
51	Polyline	51	Kigumba-Karuma	58.434	230	6	0	Bituminous	DSST	6	2	2	1	Bituminous : 1
52	Polyline	52	Karuma-Kamudini	11.088	175	3	0	Bituminous	DSST	6	1	2	1	Bituminous : 1
53	Polyline	53	Kamudini-Gulu	58.182	211	5	0	Bituminous	DSST	6	1	2	1	Bituminous : 1
54	Polyline	54	Gulu Bypass	3.956	30	0	12	Unsealed	Gravel	6	1	2	0	Unsealed : A
55	Polyline	55	Gulu-Atiak	66.917	68	0	4	Unsealed	Gravel	6	1	2	0	Unsealed : A
56	Polyline	56	Atiak-Nimule	37.172	41	0	13	Unsealed	Gravel	6	1	2	0	Unsealed : A
57	Polyline	57	Karuma-Olwiyo	51.635	45	0	4	Unsealed	Gravel	6	1	2	0	Unsealed : A
58	Polyline	58	Olwiyo-Pakwach	54.189	72	0	12	Unsealed	Gravel	6	1	2	0	Unsealed : A
59	Polyline	59	Pakwach-Nebbi	52.396	126	0	3	Unsealed	Gravel	6	1	2	0	Unsealed : A
60	Polyline	60	Nebbi-Arua	75.456	190	0	9	Unsealed	Gravel	6	1	2	0	Unsealed : A
61	Polyline	61	Arua-Manibe	5.225	336	0	14	Unsealed	Gravel	6	0	2	0	Unsealed : C
62	Polyline	62	Manibe-Koboko	53.245	128	0	11	Unsealed	Gravel	9	0	2	0	Unsealed : A
63	Polyline	63	Koboko-Oraba	19.107	161	0	17	Unsealed	Gravel	9	0	2	0	Unsealed : A
64	Polyline	64	Nakalama-Tirinyi	51.201	870	5	0	Bituminous	DSST	7	2	2	1	Bituminous : 1
65	Polyline	65	Tirinyi-Kamonkoli	38.977	922	4	0	Bituminous	DSST	6	2	2	1	Bituminous : 1
66	Polyline	66	Kamonkoli-Mbale	7.006	910	3	0	Bituminous	DSST	6	2	2	1	Bituminous : 1
67	Polyline	67	Tororo Jct.-Tororo	3.791	788	4	0	Bituminous	DSST	6	2	2	1	Bituminous : 1
68	Polyline	68	Tororo-Mbale	43.045	774	6	0	Bituminous	DSST	7	2	2	1	Bituminous : 1
69	Polyline	69	Mbale-Namunsi	5.895	2033	5	0	Bituminous	DSST	7	2	2	1	Bituminous : 1
70	Polyline	70	Namunsi-Kumi	49.32	691	4	0	Bituminous	DSST	7	2	2	1	Bituminous : 1
71	Polyline	71	Kumi-Soroti	46.532	309	6	0	Bituminous	DSST	7	2	2	1	Bituminous : 1
72	Polyline	72	Soroti-Dokolo	67.632	185	0	9	Unsealed	Gravel	8	0	2	0	Unsealed : A
73	Polyline	73	Dokolo-Agwata	23.467	175	0	9	Unsealed	Gravel	9	0	2	0	Unsealed : A
74	Polyline	74	Agwata-Lira	30.431	503	0	9	Unsealed	Gravel	9	0	2	0	Unsealed : A
75	Polyline	75	Lira Bypass	3.731	301	4	0	Bituminous	DSST	7	2	2	1	Bituminous : 1
76	Polyline	76	Lira-Kamudini	66.219	184	4	0	Bituminous	DSST	7	2	2	1	Bituminous : 1

Figure 5-7: Perplexing Semantics and Terminologies in a Database

It is not exactly clear what the difference between 'surface' and 'pavement' is from the studied databases. On critical analysis of the data records, it becomes apparent that the term surface is used for unsealed/unpaved roads and pavement for sealed/paved roads. In effect, the attribute value 'bituminous' for example is a pavement type and not surface type. This is because it refers to the type of material that covers the paved road. In the same sense, the attribute value 'gravel' is a surface type and not a pavement type because it refers to the type of material covering the unpaved surface and, bituminous is paved road material implying that the surface type should be paved/sealed. This calls for harmonisation of terminologies when datasets are to be used across organisations.

In the same database, a road section has attribute columns for both the Pav_IRI (International Roughness Index for paved road) and UNP_IRI (International Roughness Index for Unpaved road). Notice the bituminous and unsealed road surface types stored in the same database. It is true that a road may have both the paved and unpaved surface types as it is composed of different sections. But in one database, if a section of the road is unpaved, and the value for its Pav_IRI is given as 0 - remember that this indicates a very smooth road, while that of its UNP-IRI is 9 - and this indicates a very rough road, this information is quite confusing for the recipient. A very smooth road section cannot be very rough at the same time. This is a data structuring and attribution anomaly that needs consideration from the organisation's database manager.

Figures 5-8 (a) and 5-8 (b) are more examples of semantics and terminology anomalies in the datasets. The terms 'section' and 'segment' are used synonymously. Also, the term 'Road_No' (road number) in Figure 5-8 (a) is used instead of the term 'Section_No' (Section number). From the understanding of a road and link in Chapter Two, A007 is a Road_No, while A00718 is a Section_No. A road A007 may have as many sections as possible.

Attributes of ROADS

FID	Shape	ROAD_NO	ROAD	SEGMENT	ROAD_NAME	LENGTH
148	Polyline ZM	A00718	A007	18	Tororo-Mbale-Soroti-Lira-Kamdini Corner	23.458008
149	Polyline ZM	A00719	A007	19	Tororo-Mbale-Soroti-Lira-Kamdini Corner	30.884552
150	Polyline ZM	A00720	A007	20	Tororo-Mbale-Soroti-Lira-Kamdini Corner	27.004982
151	Polyline ZM	A00721	A007	21	Tororo-Mbale-Soroti-Lira-Kamdini Corner	43.91595
152	Polyline ZM	A00801	A008	1	Karuma-Packwach-Nebbi-Arua-Koboko-Ugand	51.621083
153	Polyline ZM	A00802	A008	2	Karuma-Packwach-Nebbi-Arua-Koboko-Ugand	54.43877
154	Polyline ZM	A00803	A008	3	Karuma-Packwach-Nebbi-Arua-Koboko-Ugand	1.729744
155	Polyline ZM	A00804	A008	4	Karuma-Packwach-Nebbi-Arua-Koboko-Ugand	2.967927
156	Polyline ZM	A00805	A008	5	Karuma-Packwach-Nebbi-Arua-Koboko-Ugand	48.77931
157	Polyline ZM	A00806	A008	6	Karuma-Packwach-Nebbi-Arua-Koboko-Ugand	63.888047
158	Polyline ZM	A00807	A008	7	Karuma-Packwach-Nebbi-Arua-Koboko-Ugand	5.956543
159	Polyline ZM	A00808	A008	8	Karuma-Packwach-Nebbi-Arua-Koboko-Ugand	12.955238
160	Polyline ZM	A00809	A008	9	Karuma-Pakwach-Nebbi-Arua-Koboko-Uganda	49.839477
161	Polyline ZM	A00810	A008	10	Karuma-Pakwach-Nebbi-Arua-Koboko-Uganda	18.818459
162	Polyline ZM	A00901	A009	1	Kampala-Busunju-Kiboga-Hoima	5.411836
163	Polyline ZM	A00902	A009	2	Kampala-Busunju-Kiboga-Hoima	18.682263
164	Polyline ZM	A00903	A009	3	Kampala-Busunju-Kiboga-Hoima	24.902449
165	Polyline ZM	A00904	A009	4	Kampala-Busunju-Kiboga-Hoima	0.443414
166	Polyline ZM	A00905	A009	5	Kampala-Busunju-Kiboga-Hoima	1.431595
167	Polyline ZM	A00906	A009	6	Kampala-Busunju-Kiboga-Hoima	17.672589
168	Polyline ZM	A00907	A009	7	Kampala-Busunju-Kiboga-Hoima	81.502374
169	Polyline ZM	A00908	A009	8	Kampala-Busunju-Kiboga-Hoima	26.874855
170	Polyline ZM	A00909	A009	9	Kampala-Busunju-Kiboga-Hoima	16.336357
171	Polyline ZM	A00910	A009	10	Kampala-Busunju-Kiboga-Hoima	3.120654
172	Polyline ZM	A01001	A010	1	Nsambya-Kabalagala-Gaba	0.406838
173	Polyline ZM	A01002	A010	2	Nsambya-Kabalagala-Gaba	1.769399
174	Polyline ZM	A01003	A010	3	Nsambya-Kabalagala-Gaba	0.064827
175	Polyline ZM	A01004	A010	4	Nsambya-Kabalagala-Gaba	3.804243
176	Polyline ZM	A01005	A010	5	Nsambya-Kabalagala-Gaba	1.872047
177	Polyline ZM	A01006	A010	6	Nsambya-Kabalagala-Gaba	1.20107

CULVERTS_A_B_ROADS | INVENTORY DATA C02905 | TERRAIN DATA 02 | CULVERTS_C_ROADS

ID	Road Numb	Section	Start	Feature	XSP	PL
1	A001	1	2.210	CULV	ALL	P
2	A001	2	0.170	CULV	ALL	P
3	A001	2	0.600	CULV	ALL	P
4	A001	2	1.470	CULV	ALL	P
5	A001	2	1.940	CULV	ALL	P
6	A001	6	0.420	CULV	ALL	P
7	A001	6	1.230	CULV	ALL	P
8	A001	7	0.130	CULV	ALL	P
9	A001	7	0.300	CULV	ALL	P
10	A001	7	0.580	CULV	ALL	P
11	A001	7	1.920	CULV	ALL	P
12	A001	8	0.420	CULV	ALL	P
13	A001	8	2.420	CULV	ALL	P
14	A001	8	3.420	CULV	ALL	P
15	A001	8	4.620	CULV	ALL	P
16	A001	8	6.520	CULV	ALL	P
17	A001	9	0.120	CULV	ALL	P
18	A001	10	0.121	CULV	ALL	P
19	A001	10	3.120	CULV	ALL	P
20	A001	10	4.220	CULV	ALL	P
21	A001	10	4.620	CULV	ALL	P
22	A001	10	6.220	CULV	ALL	P
23	A001	10	6.820	CULV	ALL	P
24	A001	10	8.320	CULV	ALL	P
25	A001	10	8.920	CULV	ALL	P

Figure 5-8 (a) and (b): Terms 'Segment' and 'Section' Used Concurrently

In other databases, the basic attributes for road sections are not sufficient for analyses to be made. Figure 5-9 shows an example of the insufficient attribution of two different datasets for the same road section in the northern part of the Country. The source of these two datasets is from one of the consultancy companies that preferred to remain anonymous on any publications made from their datasets. Notice the variations in coding with the FID field. These are such datasets that are prepared for CAD systems for which spatial analysis is constrained.

On a more particular note, the sectioning of the roads is confusing and not uniform. The use of sections is to provide manageable reference to road components for maintenance purposes. In order to understand the methodology adopted for sectioning of roads in the various jurisdictions, it is required that some form of documentation is provided as metadata. An important observation from an enthusiastic manager of a roads contractor company is that data requirements change from project to project for which data models become paramount for GIS to play a part. For a data model to be useful, a clear definition of terms and procedures is a prerequisite. The terms and procedures of sectioning roads in the various jurisdictions is one of the key requirements. What are the criteria for road sectioning in a jurisdiction? Is this criterion the same among jurisdictions? Is there a limit to the length of a section? Such questions need to be clearly specified in a supporting document for purposes of data exchange amongst organisations.

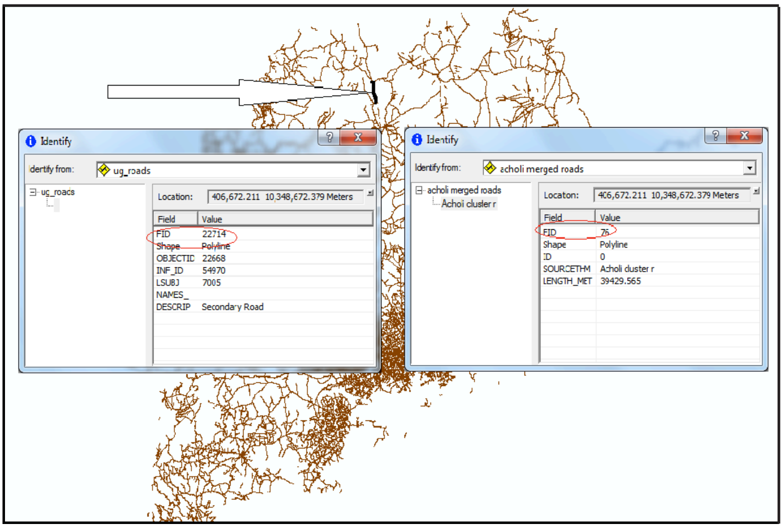

Figure 5-9: Inadequate Attribution of Roads Datasets and Variation in Feature Coding

Further still, for some organisations that have endeavoured to document their procedures for road sectioning, the locations of reference marker points have been used as nodes. Besides points that have been established by road organisations in their fieldwork exercises, geographic controls as established by NMO are used as reference marker points. However, majority of these controls have been seriously destroyed and are not existent on ground. Their previous locations are only estimated on use. Besides the errors identified in prior established GPS positions, the quantity of controls is neither sufficient for the sector. A need to rectify the errors in the existing controls and a densification of the controls is of utmost importance. This limitation was bluntly highlighted at the stakeholder's workshop where surveyors in the participating organisations urged the NMO to densify the Country with high quality controls. These controls are the foundation to application specific mapping where road maintenance lies. Additional data that is required from NMO and somewhat relevant for road maintenance was observed to include cadastral information, ownership records, and national and administrative boundaries. The present information on administrative boundaries is neither accurate nor uniform throughout the Country. By virtue of the mandate of the NMO to establish, manage and control the geodetic network and also map the roads as infrastructure of the Country, they qualify as another category of stakeholders. Their participation is quite indirect in RIM as it concerns the provision of fundamental datasets as a foundation for information based decision making.

5.3.9 Inadequate Geospatial Capacity - Human Resource

The geospatial capacity at individual, organisational and sectorial level is quite inadequate. Professionals are availed on project basis in the organisations that are privileged to host them. This usually creates a gap at the close of the project living a lot to be desired. The personnel tagged with GIS expertise in the stakeholder organisations are majorly conventional civil engineers who are trained in the areas of design and construction. In some of these organisations, it is worth noting that these personnel have been trained on the job in various aspects of GIS management such as data collection, referencing linear objects, solving interoperability issues between datasets, etc. The training in some cases has been arranged by the department although in most cases, it has been the initiative of the engineer to acquire this additional knowledge. In majority of the organisations, it is the conventional civil engineers using GIS for planning, designing, constructing, and maintaining the transportation infrastructure. Training requirements for GITs have been likened to basic applications like Microsoft Word processing where no formal training may be required. Because GIS is mainly for spatial mapping and analysis, other organisations have employed land surveying professionals and assigned them responsibility of GIS expertise. For this category of personnel, basic knowledge and management of geographic datasets is considered to be optimal. But overall, the result of untrained GIS expertise of these organisations has led to dominant challenges to coordinating how geospatial data are acquired and used. One of the shortcomings is realized in costly duplication of efforts. For example, duplicate data sets are often collected at the national and lower levels of the District, Urban and Community environments. Due to the lack of organisational partnerships and data sharing frameworks, this has become a common scenario in the sector. It is however evident that those parameters related to the inventory and condition of roads require an input from geographic data. This is because the location and the condition of roads are based on geographical position. Decisions to repair given roads are dependent on the location attribute among other factors. If GIS is to be effectively utilized, the permanent job position of GIS professional in these organisations is a fundamental requirement and not on project terms. This will go a long way in advancing the use of GITs in the sector.

The URF sector brief (Road Fund, 2011) reported the technical capacity gaps of agency staff especially for the newly created districts to plan, implement and report on maintenance activities. The district agencies are supposed to base on RAMPS to make their annual maintenance plans. 'RAMPS' is software with GIS capabilities that was developed for use by the District Urban and Community Access roads MIS project for planning and monitoring various aspects of the road. But because of no prior training, staffs of these districts are incapable of making use of RAMPS. Reported also is the low capacity of local contractors to undertake road maintenance contracts resulting into delayed and poor delivery of maintenance works.

5.3.10 Digital Divide in Perception, Adoption and Affordability of GIT among the Stakeholders

There is a distinct digital divide in the sector regarding the perception, adoption and availability of GITs. The government organisations (MoWT, UNRA, KCCA, and the MoLG) unlike private companies (the contractors and consultants) are 'richer'. They often benefit additionally from donor funds. By virtue of their position, they are more able to afford the funds to support the development of robust GITs. Although their adoption is still low considering earlier limitations discussed, they are however fast growing and experiencing a rapidly increasing demand for services. On the other hand, the consultant and contractor communities change more slowly and generate less revenue. The significant upfront costs of staffing and implementing GITs (like acquiring 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 organisations. The above scenario is what is referred to as the digital divide amongst the stakeholders in the road maintenance sector. This divide however cuts across several departments that make use of spatial data in the Country. The implementation of GITs and the related data conversion across the Country is still very uneven.

Even though they have limited role (for a short time span) in road maintenance works, some consultancy companies have benefited from collaborations with international organisations on projects where they are privileged to acquire knowledge and experiences on the potential of GITs. Roughton International for example together with PROME Consultancy and AFRICON Ltd have since 2008 worked together on the national roads databank project under which a system for management of national roads and bridges is being developed for UNRA. In this project, PROME is using the ROMDAS to collect an inventory on the national road network. Such data as the roughness and rutting measurements, highway imaging video-logs, centreline surveys (GPS coordinate measurements), moving traffic records, road inventory and Location Reference Point (LRP) data are accumulated for analysis and inclusion in the national roads data bank. The capacity of PROME Ltd has been strengthened with this project. COWI Uganda Ltd has also obtained exposure from joint ventures with international companies in which GPS units have been used for mobile scanning and surveying areas for which new roads could be constructed. The data collected was basically to be used for designing of new road projects other than maintenance. In COWI's experience, a mobile mapping system was equipped with such GIT gadgets as ladybug cameras, SICK scanners and sensors, GPS units, Inertial Measuring Unit (IMU), and precise odometers. Kagga & Partners consulting engineers are similarly involved on projects, not necessarily road maintenance, in which such equipment as hand held

GPS, differential GPS for large projects and Real Time Kinematic (RTK) are used for data collection purposes.

On the other hand, even though their role in implementation chores of road maintenance tasks is core, unfortunately, hardly any contractor has participated on any such GIT based project for road maintenance. Their take on GITs for road maintenance is centred on the fact that since the client is often interested in the finished product, then, the end justifies the means.

5.3.11Variations in Location Referencing Approaches

Approaches to location referencing qualify as inputs to standardisation of geographic datasets. However, due its utmost relevance for transportation feature management, this aspect is discussed individually as a limitation to accessing GITs for RIM. As mentioned previously, a method for linear referencing is the basic foundation for road applications especially if GIS integration is involved. For road maintenance decision making in particular, this is quite fundamental since maintenance decisions are predetermined by condition attributes relating to locations of specific points and or sections along the road. As prior discussed, there are a number of linear referencing methods, all of which could possibly be used on the same road network. However, their use should be clearly understandable and uniform throughout the databases. The linear referencing methods used for the road network in the organisations that participated in this Study are confusing and not uniform. The chainage method which is equivalent to the kilometer measure method is used in majority of the databases. The way in which this chainage is used to refer to locations along the road however differs between organisations. For one organisation, the chainage measurement starts at zero for each new section in the database. For other databases however, the chainage is continuous from the start of the road to the end. Figure 5-10 and Figure 5-11 show how chainage referencing of road condition varies between databases.

Paved Roads 01 | Paved Roads 02 | Paved Roads 03 | Paved Roads 04

ID	Road Numb	Section	Start	End	CWay_Type
1	A002	1	0.00	1.00	AC
2	A002	1	1.00	2.00	AC
3	A002	1	2.00	3.00	AC
4	A002	1	3.00	4.00	AC
5	A002	1	4.00	4.55	AC
6	A002	2	0.00	1.00	AC
7	A002	2	1.00	1.97	AC
8	A002	3	0.00	0.93	AC
9	A002	4	0.00	1.00	AC
10	A002	4	1.00	2.00	AC
11	A002	4	2.00	3.00	AC
12	A002	4	3.00	4.00	AC
13	A002	4	4.00	5.00	AC
14	A002	4	5.00	6.00	AC
15	A002	4	6.00	7.00	AC
16	A002	4	7.00	8.00	AC
17	A002	4	8.00	9.00	AC
18	A002	4	9.00	10.00	SD
19	A002	4	10.00	11.00	SD
20	A002	4	11.00	12.00	SD

Figure 5-10: Chainages in KM with Each Section Starting at Zero

Figure 5-10 also triggers back the question on the criteria for sectioning and the minimum or maximum length of a section in the organisations or sector at large. Some sections are so short, as short as 0.93 KM which implies that other factors other than the standard length of a section were used in sectioning of that road. This supports the argument that documentation on such aspects and methodologies for road sectioning are fundamental for metadata records of GIS datasets. Metadata is that data about the data that is stored about GIS datasets. It helps assessing datasets for use and in answering ill-defined constructs within the datasets.

03 Features

ID	ROAD_NO	ROAD_NAM	CHAINAGE	DESCRIPTIO	TYPE	SIZE	LOCATION	SIDE
1355	C21202	Dokolo-Namas	20.8	Junction			Point	RHS
1356	C21202	Dokolo-Namas	21.1	Place Name	I	M	Point	RHS
1357	C21202	Dokolo-Namas	25.8	Place Name	I	S	Point	LHS
1358	C21202	Dokolo-Namas	27.2	Place Name			Point	Both
1359	C21202	Dokolo-Namas	28.7	Place Name	I	M	Point	LHS
1360	C21202	Dokolo-Namas	29.7	Place Name			Start	Both
1361	C21202	Dokolo-Namas	31.2	Place Name			End	Both
1362	C21202	Dokolo-Namas	33.6	Place Name	I	M	Point	RHS
1363	C21202	Dokolo-Namas	33.8	Road Sign	I	S	Point	LHS
1364	C21202	Dokolo-Namas	0	Start of Road			Start	Both
1365	C21202	Dokolo-Namas	33.9	Road Sign	I	S	Point	LHS
1366	C21202	Dokolo-Namas	34	Junction			Point	LHS
1367	C21202	Dokolo-Namas	34	Junction			Point	C
1368	C21202	Dokolo-Namas	34	Road Sign	I	S	Point	LHS
1369	C21202	Dokolo-Namas	34	Place Name			Point	LHS
1370	C21202	Dokolo-Namas	34	Place Name			Point	RHS
1371	C21202	Dokolo-Namas	34.2	Junction			Point	RHS
1372	C21202	Dokolo-Namas	34.4	Road Sign	I	S	Point	RHS
1373	C21202	Dokolo-Namas	34.4	Road Sign	I	S	Point	RHS
1374	C21202	Dokolo-Namas	34.6	Road Sign	I	S	Point	LHS

Figure 5-11: Chainage in KM with Cumulative Measurements from the Beginning of the Road

Even though spatial location referencing is recommended for only those objects and features that cannot be referenced using linear distances and offsets, in some databases, a combination of spatial and linear referencing is done for practically all datasets. Figure 5-12 is an example of a database for which the spatial reference of latitude and longitude for the start and end of a road section exist as attributes for an unpaved road condition dataset. This is in combination with the linear reference of the start and end chainage of the road sections. Other than being a recommendation derived from road maintenance guides, e.g., HTC (2002), the accumulation of spatial coordinates of all details within a road condition database should not be a problem unless being used as the dominant referencing method. Dynamic linking of the two methods during spatial analysis in GIS is envisaged.

02 Unpaved Data

ID	Road_No	S_Latitude	S_Longitude	E_Latitude	E_Longitude	Ch_From	Ch_To	Road_Type
2112	C20126-2	0.33069	32.67371	0.29578	32.67467	2.42	3	G
2113	C20126-2	0.33069	32.67371	0.29578	32.67467	3	4	G
2114	C20126-2	0.33069	32.67371	0.29578	32.67467	4	5	G
2115	C20126-2	0.33069	32.67371	0.29578	32.67467	5	6	G
2116	C20126-2	0.33069	32.67371	0.29578	32.67467	6	7	G
2117	C20126-2	0.33069	32.67371	0.29578	32.67467	7	7.5	G
2267	B20607	-0.41703	31.12154	-0.12819	30.94755	0	1	G
2268	B20607	-0.41703	31.12154	-0.12819	30.94755	1	2	G
2269	B20607	-0.41703	31.12154	-0.12819	30.94755	2	3	G
2270	B20607	-0.41703	31.12154	-0.12819	30.94755	3	4	G
2271	B20607	-0.41703	31.12154	-0.12819	30.94755	4	5	G
2272	B20607	-0.41703	31.12154	-0.12819	30.94755	5	6	G
2273	B20607	-0.41703	31.12154	-0.12819	30.94755	6	7	G
2274	B20607	-0.41703	31.12154	-0.12819	30.94755	7	8	G
1788	C20217-1	0.21923	32.33347	0.15313	32.3994	0	1	G
1789	C20217-1	0.21923	32.33347	0.15313	32.3994	1	2	G
1790	C20217-1	0.21923	32.33347	0.15313	32.3994	2	3	G
1791	C20217-1	0.21923	32.33347	0.15313	32.3994	3	4	G

Figure 5-12: Spatial and Linear Referencing Methods Combined

The locations of posts along the roads have been captured as reference features along the said roads. Even though the point that this section is raising is to do with the challenge of variations in location referencing methods, this is a strength factor that indicates the appreciation of location referencing as fundamental in GIS applications with road maintenance. As indicated in the data collection form in Figure 5-13, some LRP positions like the intersection of roads, start/end of bridge and railway crossing, have been captured for possible location referencing. Notice also the chainage locations of these features.

Road Inventory Data

Road Name.: Bweyogerere-Bukasa Date.: 08/05/2008

Road No.: C20126 Inspector.: S/A/F

Description.: Start of unpaved at St.Joseph P/S

Chainage (km)	Feature Description	Type	Size/Width (m)	Location (P/S/E)	Side (LHS/RHS/ Both/C)	GPS Coordinate WGS84 (dd.ddd)	Comments
2.42	Start of unpaved			Point	Both	E032.67371	
3	KM Post(3Km to Bukasa)			Point	LHS	E032.67574	
4	KM Post(2Km to Bukasa)			Point	RHS	E032.67370	
4.21	Junction to Bukasa P/S			Point	LHS	E032.67397	
4.8	Junction to Bukasa TC			Point	LHS	E032.67318	
5	KM Post			Point	LHS	E032.67205	
7.5	End of Road			Point	Both	E032.67467	

Figure 5-13: Location Referencing Posts as Features along the Road

Overall, the sector needs to come out clearly on the linear referencing method used for roads datasets taking into consideration the basic requirements for an effective linear referencing method as put forward in Chapter Two.

5.4. Potentialities and Opportunities for GIT in RIM

As highlighted in the chapter on methodology, the motivation to the data collection method adopted for this Research was backed by innovation and exploration of the potential of GITs for RIM. As earmarked by Goodchild (2000b), one of the challenges of current research in the field of GIS-T is the response to new technologies. Chapter Three of this Thesis has evidenced some GIT innovation projects in line with various road applications. Technological and methodological excerpts from those projects formed the basis of the adapted method for independent road mapping as observed in Chapter Three. These excerpts also raise products that are worth investigating as further research on the subject matter of GITs applied as decision support tools for RIM. These methods have been tested within this Study but not proven. This section presents some of the methodologies used and GIT datasets collected and recommendable for further exploration both by researchers and personnel in the RIM sector. The idea is to enhance the use of GITs in RIM in a bid to stretch beyond the traditional data collection, analysis and presentation methods.

5.4.1 Geo Tagged Photographs

The fast development and use of Google Maps has created an environment where geo tagged products can be visualised for decision making. With the use of a high resolution camera fitted with GPS (Nikon Coolpix 6000, 13.5 mega pixel), photographs of points and sections of concern were taken. The geographic location is stored together with other **Exchangeable Image File Format (EXIF)** data in the header of the JPEG picture. EXIF (EXIF, 2012) contains metadata of the image. It is a standardised format for still pictures. The points and sections data included black spot locations and areas of severe road condition like large potholes. Additional photos of location reference points could also be taken and archived in databases for future reference and analyses using database queries.

Some freeware tools were identified during this Study for which visualisation of these archived photo datasets is possible. An example is GeoSetter (Geosetter, 2009), a freeware tool for windows for showing and changing data of image files e.g., images taken by digital cameras. It has special emphasis on geographical data which includes a Google Map feature that shows where the picture was taken. 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. Working with Google Maps requires internet connectivity which has already been observed as not sufficient for various applications in the Study area. This however should not limit recommendations to advancing GIT use. This is primarily because ICT is generally advancing at a faster rate today. For example, the internet bandwidth in the Country has enormously increased from 2008 when this Study commenced, to now 2012. With GeoSetter, it is also possible to set geo data by embedded Google Maps or by entering known values for coordinates and altitude directly. 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 5-14 shows the main window of the GeoSetter interface and geo tagged photograph of Eng. Zikusoka road in Jinja, Uganda in the display.

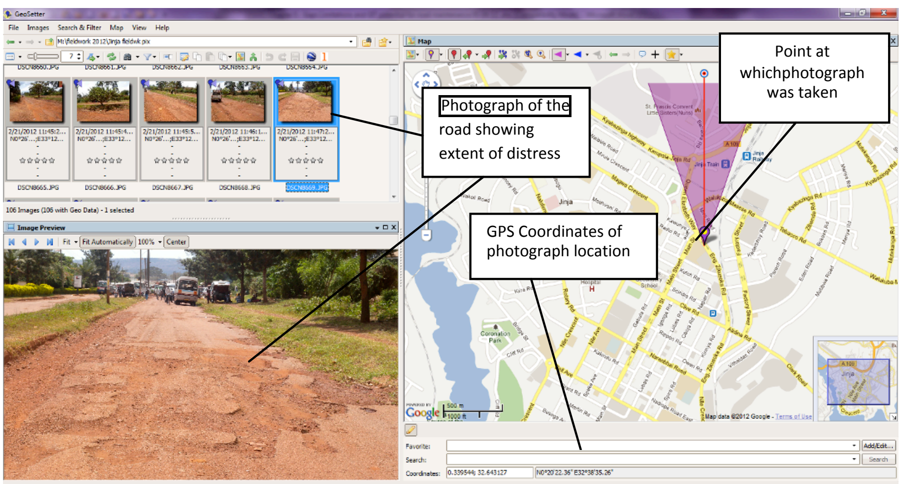

Figure 5-14: A Screenshot of the Geosetter Main Window

GeoSetter also allows you to save critical locations and apply this data to other photos with just a click of a button. This feature is particularly important for road maintenance decision makers who may need to regularly take photos in specific areas. Even if images do not contain GPS or any other geo data, it is possible within Geosetter to edit virtually any other aspect of the image's data. Double-clicking an image opens its edit data page, and this offers tabs for editing location, source/description, categories/keywords, contact, date, and custom view, which allows for selections from the other tabs' entries. The basic interface of Geosetter is divided into 2 halves. A file browser and image preview panes on the left and an embedded Google Map on the right. A provision for these photographs has been made in the data model presented in Chapter Seven.

Visualisation for decision making using these photographs can additionally make use of the increasing number of free geotagging and archiving software e.g. Picasa 3, Microsoft Pro Photo Tools (Microsoft, 2012), GeoImgr (GeoImgr, 2012), and Google Earth. Sony GPS embedded equipment also often comes with software to manipulate the photo and video product. Contour (see Section 5.4.3) has also come up with own solutions to video geotagging capabilities. A standard format like EXIF for video is yet to be established.

5.4.2 Mobile Mapping Methodology

Using digital cameras, GPS units, a laptop computer installed with GIS software and a vehicle pick up cabin as platform; a map document of a section of the Study area was prepared. This was an output of the field work exercise in which an independent mapping of road sections within the Study area was made as a check on the reality and quality of the GIS datasets in existence. The mobile mapping methodology involved the use of a vehicle (pick up double cabin with guard rails – see Figure 5-15, two digital camcorder (a Canon HF 11and 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).

Figure 5-15: Cameras Mounted on the Guard Rails of the Vehicle

The Sony camera was modified to record IR and the Canon was maintained with real colour. The reason for the use of these 2 cameras was for stereo comparison of real and infrared imagery of the captured road sections. The IR camera was intended to capture the road shoulders besides the carriageway which ordinarily would not effectively be registered with a RGB camera because of the vegetation interference. The presented methodology herein was adapted on failure to acquire flight clearance for the low flying paramotor which was the initial platform plan for the mobile mapping videography methodology. 2 GPS devices were used for backup of the captured GPS positions and increased precision of the road centreline. Details of these GPS equipment are provided in Chapter Four.

Meanwhile, the GPS loggers were synchronized with the GIS on the notebook computer to allow for tracking of the vehicle path and making of annotations at LRPs and important road features & architecture along the road. In the computer was the ArcGIS map document with a satellite image (Landsat ETM+) and road dataset shapefiles from various organisations in the background. The Landsat ETM+ satellite images covering the Study area were downloaded from Ground Land Cover Facility (GLCF) as mentioned in Chapter Four. As the vehicle tracked the road centreline, the path followed was highlighted by the GPS tracks. These tracks are shown by the thick road line in the field base map document in Figure 5-16.

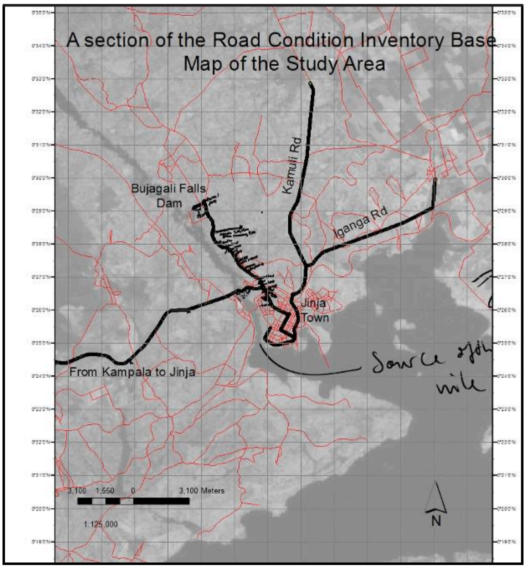

Figure 5-16: Field Map Document

For purposes of road inventory and location referencing, annotations of important features along the road were made. This map document was visualised back in the office together with the rest of the datasets from the other organisations and was found informative.

The results from this mobile mapping undertaking were presented and discussed at both the stakeholder's workshop and the conference on advances in Geomatics research (Kayondo et al., 2011b). In this paper, an attempt was made to contrast this low cost mapping methodology with the ROMDAS. The product from this methodology can be used for preliminary road maintenance decision making purposes. In the process of annotating the map document, sections or points of visibly severe condition were highlighted too. Besides inventorying the condition of the entire road stretch, the idea was to map an image from the field base map, from which sections of the road that need further inventory or in-depth analysis to ascertain the scope of maintenance works to be performed could be ascertained. Other earmarked applications of the methodology and products were identified as planning of fresh road designs, widening and realignment of roads. Further use of the methodology in these and more road applications need to be explored.

The COWI consulting representative at the stakeholder's workshop likened this mobile mapping methodology with their research in collaboration with internationally based organisations that preferred anonymity. The Research involved the mapping of the road network with various GIT embedded gadgets that were clamped and housed in a vehicle. Their pilot project was intended to collect data to be used for designing of new road constructions. From their results, levels of the terrain were obtained and together with their visual observations that were not documented, these details were to be matched for road designing back in the office. This among other discourses put the labelled low cost mobile mapping methodology in perspective. In contrast with still imagery, for motion pictures (video), a similar, standardized metadata format like EXIF is still to be established. Several brands however, like Contour (see Section 5.4.3) and Sony have however released own solutions, both of which were applied in this Study.

5.4.3. ContourGPS Camera Products

The methodology above advocating for preliminary maintenance decision support can be made robust with the use of the Contour GPS camera (ContourGPSCamera, 2011). The contour GPS camera captures exquisite 1080p video utilising a 135° wide-angle rotating lens recording in full High Definition (HD) quickly adjusting to changing light conditions when out in the field. The wide angle rotating lens delivers a true high quality image that captures all the road furniture with minimal distortion. The use of this camera provides for video mapping from a very small and light GPS video camera.

The tracking capability of the ContourGPS adds speed, location and elevation to the video. It is set up with a GPS receiver which auto-maps the three essentials - location, speed and elevation - at up to four times per second in order to create a continuous track of coordinates. Additional to the 1080p at 30 frames per second, the location-based camera utilizes an advanced processor to record a clearly defined video at 720p at 60 frames per second. With internet connectivity, contour GPS has the ability to synchronize with one's footage of the recording platform to provide a second-by-second replay of the road traversed via Google Maps.

The camera comes with software applications for mobile connection which with the Bluetooth capability, is possible to check the wide angle on a smart android phone screen before taking off with the mapping. The contour application creates a wireless handheld viewfinder that enables you to align your track to make sure you have the right angle to the road thus eliminating guesswork. With this Bluetooth capability, it is also possible to configure your camera settings in real-time and preview what your camera sees, while in the vehicle platform and from all the most remote locations. The camera has a number of accompanying products for use in different environments. Refer to ContorGPSCamera (2011)

The camera was specifically designed for field conditions (see Figure 5-17), with a husky aluminium body that withstands rough conditions and a water-resistant design that sheds all types of precipitation and moisture. For research that requires mapping under water, a waterproof case which provides sufficient dryness up to sixty meters deep can be acquired.

Figure 5-17: The ContourGPS Camera after Rugged Fieldwork
Source: http://contour.com/products/contour-gps

Like many video recording cameras, the contour GPS has a built in multi-direction microphone that captures ambient audio. In reference to the vast amounts of data collection on the road condition, a lot of space is needed to archive and manipulate these data. The 2 GB micro SD memory card provided is expandable to 32 GB, and captures up to eight hours of video when shooting in full 1080p. The recorded video is easily downloadable on computer and a platform for sharing the video is provided on contour.com sites. However, for purposes of our road condition inventory surveys for maintenance decision support, these videos can be archived and data mined for future use. In Chapter Seven, as with the geo tagged photographs, these video types have been provided for in the developed data model.

The use of this ContourGPS camera was tested on some roads in Kampala and Jinja. Since the presence of potholes on a road is an effective indicator of the poor condition of the road, its use was targeted to visualise the depth of potholes. This was accomplished using stereo video as produced by two ContourGPS cameras mounted on the upper edge of the windscreen of a vehicle using windshield mounts. Figure 5-18 shows a windshield mount for the contour camera.

Figure 5-18: A Windshield Suction Cup Mount for the ContourGPS Camera
Source: http://contour.com/products/suction-cup-mount

A stereo video is that which endeavours to show images in a 3D impression thus enhancing the illusion of depth. The picture in Figure 5-19 shows the two windscreen mounts clamped at the left and right sides of the vehicle windscreen.

Figure 5-19: ContourGPS Camera Clamped on the Vehicle Windscreen

As is the rule of thumb in stereoscopy that an optimal stereo base is when the distance between the lenses/eyes for a human being is 30 times smaller than the distance to the objects, the two cameras were placed at a distance 30 times smaller than the target location on the road in order to achieve stereo video of the mapped roads. For the experiment in this Study, a target distance of 15 meters in front of the vehicle was set. The cameras were therefore placed 50 centimeters (1500cm/30) apart. Also, since the cameras were clamped on the vehicle windscreen, their inclination to the horizontal was critical to avoid recording of the vehicle bonnet. The best inclination angle below the horizontal was identified at 5^0. Recording from the two cameras was started at the same time to ensure that they both record the same length of video. For purposes of making the stereo, a white board indicating the origin and destination of the video, was slammed in front of the cameras. It was at this point of slamming that the right and left images were manipulated into stereo using the Stereo Movie Maker (StereoMovieMaker, 2012). The Stereo Movie Maker is used for processing stereo movies from video captured with left and right cameras.

Figure 5-20 is a screenshot of one of the videos as viewed within the contour story teller (ContourStoryTeller, 2012).

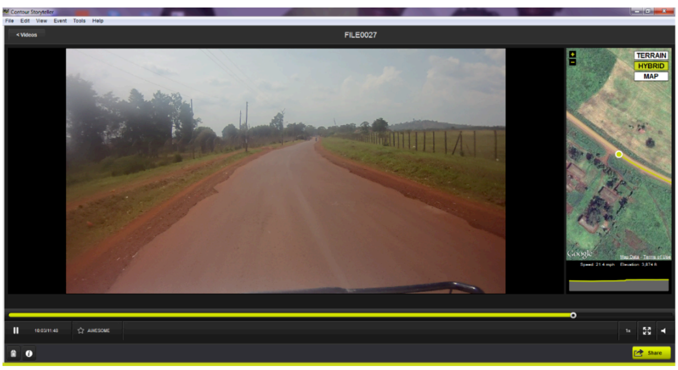

Figure 5-20: Screenshot of a Contour GPS video captured along Jinja Bujagali Road

Notice the position of the car as a round dot along the road in the hybrid Google Maps window in Figure 5-20. Notice also the farm on the right hand side of the road in both the video and the Google Maps window. The wide view of the camera is also evident from the capture of the road shoulders other than the carriage way.

Contour story teller is a freeware that brings video and its location unitedly at ago. It allows the viewer to watch GPS videos in interaction between the map and the video player. For purposes of road condition inventories, it is possible to fast forward the video to critical sections of the road for in-depth analysis. In addition to visualisation, the video can suitably be edited and shared with colleagues in the same field through uploading to contour.com. While housed at contour.com, the video can be shared with anyone through various ways like copying and pasting of the video link and YouTube. Contour story teller has the capability of configuring the ContourGPS camera by adjusting its audio, lighting and video quality. This is a unique functionality for contour cameras. Unfortunately though, this archiving capability of the contour story teller is only currently capable for reading and displaying GPS data that has been saved with Contour cameras. Storyteller cannot receive GPS data from a 3rd party device. Even though it has not been used for more professional applications like producing decision support products as is proposed in this Study, it has widely been used in sports to track races of participants. To-date, the camera costs $299. 99 USD which, considering the vast amount of information to be obtained from its products, is conceived to be cost effective for an organisation tagged with road maintenance.

Figure 5-21 is a screenshot of a stereo video where depth can best be perceived using 3D polarised glasses that are available on the market. However, this requires a special monitor. Polarised glasses cause the eye to concentrate about two contrasting positions hence the 3D depth impression. When anaglyph, meaning that the two videos or pictures for the left and right are produced in contrasting colours, cheap anaglyph spectacles/glasses can show stereo with every screen.

Figure 5-21: Screenshot of a Stereo Movie by Stereo Movie Maker Captured along Jinja Bujagali Road

5.4.4 Depth Records with the Kinect

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, RGB camera and 3D video sensors which are basically scanning the vicinity and producing depth models. This Research investigated working with the Kinect to capture both visual road condition from the RGB camera and the perception of roughness and extent of potholes from the 3D sensors. 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 methodology adopted 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 in the infrared part of the electromagnetic spectrum, together with the traffic is obviously eliminated. Figure 5-22 shows the Kinect equipment.

Figure 5-22: The Kinect Xbox 360 Video Game Console

Figure 5-23: The Nyko Wide Angle Lens Placed Infront of the Kinect

The Study has attempted to calibrate the Kinect in order minimize noise in depth measurements. It was established that the Kinect should be placed at a minimum height of 0.48m above the location whose depth values were to be obtained. It was ascertained that for optimal visibility of the road width, the Kinect should be clamped as far high as the width of the road to be surveyed. This literally implies that for a road width of 5m for example, the Kinect should be placed as high as 5m above the ground in addition to the 0.48mimimal height distance. As the width of road varies between sections, it could not be guaranteed how far high to connect the Kinect. Additionally, this caused instability of the equipment. The use of a Kinect's wide angle lens was identified as a means to reduce the height at which to clamp the equipment. It widens the angle of vision of the Kinect, allowing it to be clamped at a convenient position to optimise both visibility and stability. Figure 5-23 shows the Kinect with nyko wide angle lens in use.

Figure 5-24 (a) and (b) are pictures of the Kinect's preliminary testing on Swedish roads before use of the nyko and the improved system as was tested on the Ugandan roads respectively.

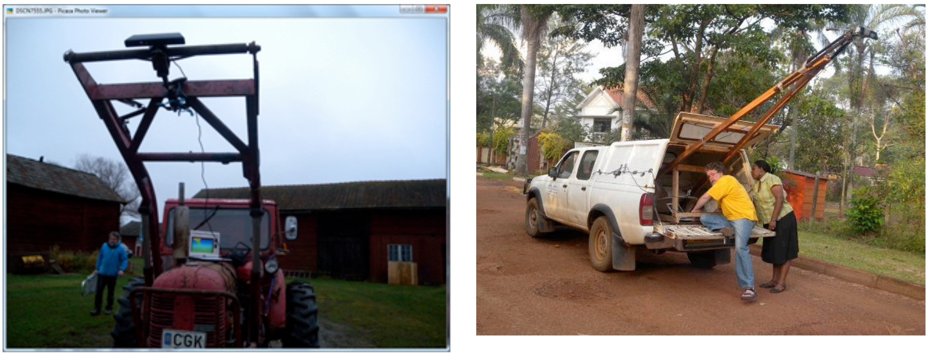

Figure 5-24 (a): Preliminary Testing of the Kinect on North Sweden Upcountry Roads and (b) Kinect Mounted on Wooden Stands Fixed at the Back of a Vehicle Pickup Cabin in Jinja-Uganda

Kayondo et al (2011b) anticipated challenges with irritating traffic and interference of the solar radiation in the infrared part of the electromagnetic spectrum on experimenting with the Kinect. The challenge relating to traffic was eliminated by choosing road sections in the residential parts of the Study area that were not dominated with many vehicles. The solar radiation could also be managed by filming at specific times shortly before sunrise and after sunset. Also, the means to record and save depth and RGB measures of the Kinect Xbox 360 using brekel[6] and rgbd 6.0[7] were not productive due to the high frame rate of 30Hz.Other models of the Kinect- Kinect for windows 1.5 have been produced which can allow developers to record, play back and debug clips other than the screen dumping methodology that was used in this Study's experiment. A non-commercial Software Development Kit (SDK) for this version of the Kinect is available. This Study's findings suggest that further experimenting with the Kinect will produce beneficial results such as pothole size estimation and further for cost calculations during road maintenance. Synchronising the recording with external GPS tracking equipment should be able to give the location of the pothole in consideration. The screen dumps saved from the Kinect Xbox 360 were used to develop 3D models of the recorded potholes using Autodesk 123D catch (Autodesk 123D Catch, 2012) free software. A screenshot of one this 3D model is shown in Figure 5-25.

[6] http://www.brekel.com/?page_id=155
[7] http://labs.manctl.com/rgbdemo/

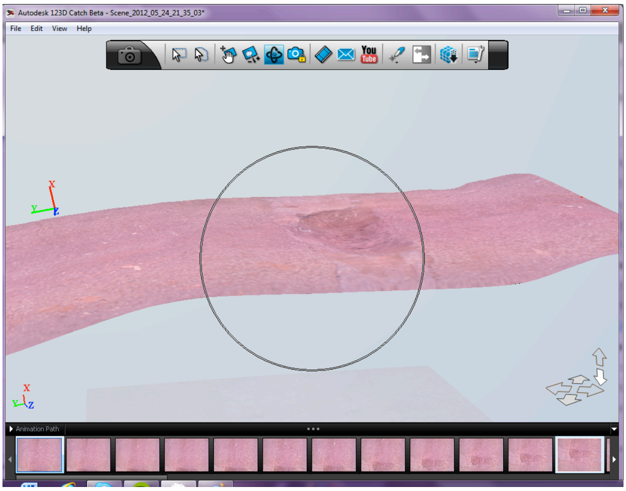

Figure 5-25: Screenshot of 3D Model from Kinect Screen Dumps

Several other software e.g. Microsoft Photosynth (Photosynth, 2012) are freely available for producing such depth models for better visualisation at different angles, animated imagery and quick calculations for decision making. R&D in the RIM sector should be emphasized to ensure that STI are maximally utilized for informed decision making of road maintenance.

5.4.5 Research and Innovation Department - Swedish Road Transport Administration

In a bid to borrow good practices from Sweden, the country in which the sponsoring body of this Research resides, and that in which much of the Research writing was done, some consultations in form of interviews were conducted with some road maintenance organisations. Of particular interest to this Study was the interaction with the managing director of SweRoad, the National Swedish Road Consulting organisation which is a subsidiary of the National Swedish Road Administration. The business idea of SweRoad is, based on the international market, to offer Swedish know-how to the transport sector, mainly on roads. The Swedish transport administration, the government authority responsible for construction and maintenance of state railways and roads in Sweden has assumed some recommendations of the SweRoad. This Authority also handles the supervision of government subsidized municipal and private roads. The knowledge of the existence of the Swedish Transport Administration's research and innovation (R&I) department under the SweRoad was a good finding. The aim of the R&I department is to furnish the sector with knowledge of new and improved services, products, methods and processes of handling tasks. These make it possible for the administration and society to efficiently achieve goals and meet new challenges that are ordinarily expressed in new policy demands. The needs of operations, citizens, and the business sector can always be addressed through R&I. R&I in the department focus on problems and challenges identified at both strategic and operational level. They range from applied science to innovations on the market. It is to be noted that no such department exists in the road maintenance sector of Uganda even if it could have the potential of fostering the development of robust GIT applications in road maintenance operations.

5.5 Concluding Remarks

The gaps in GIT use for road maintenance have been observed to include absence of data sharing and collaboration, inadequate involvement of GITs in the routine road maintenance activities, inappropriate institutional arrangements & partnerships, and lack of a standard framework for geographic datasets. The supporting framework includes defining common data structures, formats, standards and terminology which are fundamental in the establishment of a SDI for the sector. The limitations discussed are inclusive of those factors that are not clearly envisaged as affecting GIT use and yet consultative interactions instituted them clearly. Concerns such as policy, GIT digital divide in terms of perception, adoption and affordability, budget limitations coupled with unconventional maintenance plans, supporting infrastructure and geospatial capacity are limitations faced by GIT in RIM. Following from the above discussions, these limitations are also noted to affect GIT operations in several other applications involved in spatial data production and use. This is because GIT use varies marginally for various applications making the challenges faced between different applications to be similar. For effective and efficient use of GITs in the sector the above gaps need to be closed. The next chapter presents a methodological framework for enhancing the use of GITs in road maintenance. The framework is largely based on bridging the gaps and limitations discussed in the present chapter. It comprises of strategies developed from interviews, FGD, field observations, reviews of sectorial documents and the workshop proceedings. Extracts from literature on experiences and successes of GIT initiatives in various disciplines are also adapted as part of the framework.

CHAPTER SIX
METHODOLOGICAL FRAMEWORK TO ENHANCE GITs FOR ROAD MAINTENANCE IN UGANDA

6.1 Introduction

This Chapter presents the developed methodological framework to enhance GIT for RIM in Uganda. The framework development assumed a mode 2 knowledge production line where the context of the problem was the background to developed strategies. Through findings from interviews, FGD, field observations and measurements conducted in the Study area, the framework components were derived. Additionally, a review of various literature on effecting GIT applications in organisations was made. This review provided input into the evolved framework. The framework is basically a set of components, strategies and guidelines earmarked for enhancement on the use of GITs to further the sector in spatial decision making. Concepts of SDI as discussed in Chapter Two have been used to back up the framework components. It consists of a total of 6 components whose presentation herein does not call for the exact order and priority of implementation but anticipates for horizontal undertaking and supportiveness amongst each. Since GIS is a generic technology, its applications are analogous to other fields handling spatial dynamic data, this framework is adaptive for the vast organisations for which it is deemed fit. The framework additionally builds on the factors of successful GIT implementation by Sieber (2000), Onsrud and Pinto (1993), Crosswell (1991 and Budić (1994), which include long term commitment from upper management, sufficient allocation of resources, adequate staffing, timely and sufficient training. For some of the framework components, a lead role organisation has been recommended and tagged with spear heading the defined strategy. Overall, the awareness of the value of spatial information, GIT and the relationship between GIT and SDI, cooperation between the various stakeholders (partnerships), and involvement of the politicians concerned is crucial for realization, acceptance and development of GITs in the sector. Political support in form of policy enactment provides legitimacy and encourages the necessary financial investment for developments in Uganda. This Research envisions the same political benefits for GIT advancement.

6.2 Policy on GIT Usage for RIM

Support structures do not emerge and continue to exist automatically (Eric de Man, 2000), they need political commitment (Yeh (1991), Sahay and Walsham (1996), Campbell and Masser (1995) and Rajabifard and Williamson (2001b). This political commitment in the case of Uganda could be in form of policies. The setting up of a policy on the obligatory use of GITs by all stakeholders in RIM should emphasize aspects of copyright, privacy, pricing and standards. This is because geographical data has to be shared amongst organisations and individuals. The enactment of relevant policy components to this effect could be the first step towards enhancing the use of the prior mentioned technologies. In the conceptual framework for understanding inter-organisational GIS activities by Nedović-Budić and Pinto (1999a; 1999b), policies are earmarked as one of the coordination mechanisms. Nedović-Budić and Pinto (1999a; 1999b) summarise some issues for which policies will need to be developed, agreed upon and implemented if some level of joint GIS and database activity is to be exercised. These include data, responsibility, ownership, contribution and incentives. In context with GIT for RIM, policies on data, ownership and responsibility are of concern.

The need for data standards is paramount for GIS use and data sharing. They determine the fitness of data and, if developed well, they reduce the costs of data sharing between the different users as issues relating to data interoperability are in effect solved. Centrally important is a policy component on data standardisation within the road maintenance sector. As prior identified, there are many national and international organisations and communities with different scopes seeking to establish standards for GIS. Consequently, each concentrates on a particular aspect of GIS. These diverse scopes are one of the reasons why none of the existing standards can be applied alone to GIS-T without adaption. "Specifically there is no standard yet available for GIS-T, which includes all of topology, linear referencing systems, graphical representation of road segments and abstraction levels of information issues"(Demirel, 2002, p.33). Even within a SDI, the importance of data exchange standards alongside the data itself (Davis and Fonseca, 2006) is fundamental!

Likewise, an enactment of a policy component to guide the various responsibilities necessary to realise the developed framework strategies is equally vital. These are policies related to deposition of data, user support, decision making, database development and maintenance. The policy could spell data collection guidelines emphasizing the use of GPS, aerial photographs, satellite imagery and GIS. Even though participants at the stakeholder's workshop mentioned in Section 4.3.5 were of the opinion that the policy should not give a direction to the exact technologies and procedures to be adopted, but a universal translator, operational or international guidelines; the former position is adhered to in this Thesis. This is because in the long run, GITs could be used in routine support of policy making, a stage that would be pretermitted if the policy position is ignored. A quote to this effect from Pollitt (2010) "Indeed, even when technological change is initially undertaken with the official aim of simply improving the delivery of existing policies, it may nevertheless lead to subtle or sometimes substantial changes to those policies". In other words, policy change sometimes follows from prolonged implementation of technological changes rather than the obvious way round. Similarly, Sieber (2000) asserts that through the sophistication of analysis and presentation of powerful images, the greater promise of GIS (read GIT) technology may assist in influencing public policy. The reasoning for differing policy proposals by stakeholder participants is due to the fact that some of the GIT openings like the use of ROMDAS are borrowed and not developed locally for which mandatory policy assertion for their use may not yield much. However, there are several basic GIT that are readily available within the sector for which policy directive on their use would further GIT use for road maintenance.

The form of policy to adopt however should remain a choice by the implementing bodies. Often though, policies between organisations involved in joint GIS can be either: a) formalized, documented, and guided by prescribed procedures and designated cross organisational entities; or b) implemented as unwritten rules and verbal understanding of mutual conduct and obligations with no coordinating cross-organisational entity (Nedović-Budić and Pinto, 1999a). Otherwise, memoranda of understanding have been the most common documents that are used to formalize GIS activities between couples of organisations.

Even though most GIT projects have ended up in frustration for the organisations involved, it is advisable that the whole conception begins with a similar setting which is currently working well for UNRA under the project of setting up a national road's data bank. Project requirement for the institutionalization of GITs is advocated for by Eric de Man (2000). As with any new technology, the technical paradigm shift requires an equivalent re-engineering of the business processes to take full advantage of it (Sutton, 1997). The institution should beware of this paradigm shift in the process of institutionalisation. By institutionalization of GIT applications, Eric de Man (2000) refers to the process whereby the GIT activities become so rooted in organisations such that they have a strong and normative impact within the group or society on problem solving behaviour (ibid). This understanding is somewhat different from the tradition that refers to institutionalisation as those conditions for effective implementation and utilisation of GITs. This Study refers to institutionalisation as an on-going process within the organisation and not an end in itself. Also, Clodoveu and Fonseca (2006) make conclusions on how successful SDI begins as application driven projects. The take home idea here is that the enactment of GITs policy components should make use of project driven approaches to ensure institutionalisation of GITs.

The use of consultants in policy formulations will additionally impart value to the enacted components. The consultant is assumed to be more knowledgeable and skilled in the profession of expertise and as such, their advice on operational policies, national statute, local circumstances and their leadership in general is significant. They are conversant with best practices and aware of the problematic transferability of such practices amongst organisations. Often, from experience, consultants are equipped with methodologies or frameworks for problem identification from which they derive more effective and efficient means to perform tasks. For GITs to take effect this overview of consultants is beneficial to the sector. At this level of the road maintenance sector, the use of consultants is desirable to review organisational goals, assess needs, offer alternatives, and develop strategy. Involvement of consultants will give the sector a foundation on which organisations may build the GIT conception. In Onsrud and Pinto (1991), the use of consultants to guide or participate in feasibility studies was recognised as essential.

6.3 Capacity Building in GITs

The expertise of an organisation's human resource is quite vital in founding technologies and methodologies of organisational tasks. Besides evidence from this Research's findings, the statement by Dunn et al (1997, p.156), "Human resources and expertise underlie all organisational, data and technical issues on GIT implementation", is in agreement. Expertise entails both knowledge on GIT benefits and the science involved in executing these technologies. Staffing of organisations involved in GIT use is particularly important and researchers, as reviewed in Chapter Three, have even gone an extra mile to research on various models on how this should be effected. What is successful in one organisation however may not work in another. This identifies significant importance of combined capacity building (or development) methodologies in organisations where enhancement of technology interventions is being advocated for. In the present Study, it has been observed that, the contractor category of the involved stakeholders has limited knowledge of the benefits of GITs let alone the functionalities of the technologies themselves. Capacity building for this category of stakeholders could begin with diffusion. As cited by Onsrud and Pinto (1991), Zaltman et al. (1973) define diffusion as the process of communicating an innovation to and among the population of potential users with an aim of it being adopted. For the rest of the stakeholder categories, the approach to capacity development should harmonise the exploration of appropriate uses of GITs in the context of other application areas with grounding hands on GIT practice in the road maintenance sector to ensure that all the necessary personnel are educated and trained. Issues like choices of hardware and software must be communicated. The ethics, limitations and applicability of systems must also be clearly understood. This Knowledge of hard-technology consisting of the hardware and processes, and soft technology consisting of know-how, as well as management, technical, professional, and other skills (Groot and Sharifi, 1994), is profound.

6.3.1 Diffusion of GIT

Diffusion is the process by which an innovation is communicated through certain channels over time among members of a social system (Rogers, 1993) as cited by Chan and Williamson (1999). According to Campbell and Masser (1995) and Chan and Williamson (1999), diffusion should be an umbrella concept encompassing the processes of raising awareness, adoption, implementation, routinisation and utilisation and an evaluation of the outcomes. Before engaging in focused capacity building programs, the contractor category of stakeholders should attain a level of awareness and knowledge of the potential of GITs. In fact, the ultimate achievement of GIT diffusion is the embodiment of the technology into the organisation's business processes (Zwart, 1993) as cited by Chan and Williamson (1999). The detail on models and scope of diffusion is not the subject matter of this Research. Through diffusion processes, the organisations' business processes, their preparedness for GIT implementation, positivistic individual perception and attitudes of the technology should be established as foundation for continuing capacity building mechanisms. Igbaria and Nachman (1990) as cited by Sieber (2000) contend that employee acceptance of technology has been correlated to successful usage. Technology resistance on the other hand has been found to suspend the most technically advanced systems (Er, 1989). These background references call for the necessity to have the contractors as stakeholder in road maintenance, understand and accept the involvement of GITs for better decision making in the sector.

Diffusion involves identifying and dealing with critical social factors and processes in the adoption, implementation and utilization of the technology. Literature indicates that when diffusion initiatives are undertaken, decision making responses of individuals, groups and organisations may be predicted and, therefore, may also be accommodated or redirected through prescriptive strategies (Onsrud and Pinto, 1991). This attribute envisaged from the implementation of diffusion mechanisms is in support of the strategy to kick start capacity building through diffusion. Continued capacity development with other organisations within the sector could then proceed as articulated in the following sections.

6.3.2 Continued Professional Development (CPD)

To maintain the expertise of the technical personnel in the GIT departments of the RIM sector, Continuing Professional Development (CPD) should become an integral part of the processes of enhancing geospatial capacity. Continuing Professional Education (CPE) or CPD is the means by which the knowledge and skills of professionals are maintained throughout their professional undertaking. It is the systematic maintenance, improvement and broadening of knowledge and skill, and the development of personal qualities necessary for the execution of professional and technical duties throughout one's working life (Crossley and Hollway, 2000). CPD is a framework for, or approach to, lifelong learning, the on-going self-directed, structured, outcomes-focused cycle of learning and personal improvement (Rouse, 2004). CPD aims to maintain professional standards of practice, individual competence and further one's knowledge and skill in the profession. Both the structured and unstructured mechanisms should be enforced. Organised structured CPD is planned and arranged professional development by either the organisation where the professional is working or the organisation that is delivering the training. The unstructured CPD, on the other hand, involves self-initiated or directed learning by the professional. It may include individually defined projects and personal reading. Fortunately, this later practice has been registered in one organisation that forms part of the interviewees of this Research work. The consultant learnt GIS on the job and continually uses 'Google' and other means to keep informed of new software, data, analyses, etc. that are developing in GIT. Subscriptions to newsletters and software update forums have kept the personnel in the know. Overall, CPD initiatives in the sector could take the form of individual readings, action research, seminars, workshops and conferences. The rate of change of the technologies should in principle be a guiding factor to the amount of CPD recommended for the individuals in the organisation.

For starters, organisations that provide professional training on geographic information sciences, such as universities and private companies, should be encouraged to set up customised courses for GIT in RIM. Makerere University for example, through the University GIS centre conducts customised courses in GIT applications for various application domains. Local governments have for instance been trained in the application of GITs for urban planning. There are also some private companies like Geo Information Communications (GIC) that are conducting training to various organisations in GIT applications in specific domains. GIC is an Information Technology-based Company with a focus on providing solutions and services in the area of GIS, RS and related applications. Universities and such companies should be strengthened and linked to organisations in RIM. This linkage should be able to advance the triple helix concept of government, academia and industry working together for sustainable development. As suggested by Harvey (2001), the social coordination of GIT relies on collaboration between actors from the public, private, and education sectors. This definitely requires a budget as is discussed in Section 6.6.

6.3.3 University Collaboration

Public universities should initially become a focus for capacity development including training and research in GIT. This is because they are mainly government funded for which policy directives from government can be easily realised. In due course, private universities with the means could as well partner with the participating organisations to undertake capacity building. The MoWT is earmarked to coordinate the efforts of these universities to achieve this goal. In course of this collaboration, a recommendation of research priorities should be through consultation with the stakeholder organisations. The research undertakings should in effect be handled collectively by both the university and the organisations involved in road maintenance. More so, these universities should be involved in the various data management and usage networks of the RIM organisations. This form of collaboration will benefit the establishment of a SDI for the sector (see Section 6.4). The evaluation of curriculum design and content should be an on-going activity basing on the advancement of GIT usage in the sector. This should also require input from the sector to ensure that graduates from the University are well equipped with knowledge that is aligned to the roles in the respective organisations. According to Leitner at al. (1998) and Ghose (2001), university partnerships are deemed advantageous in several respects including easier access to the rich potential sources of GIS expertise at the University. In search for innovative approaches and solutions relating to data transfer standards, interoperability, semantics and ontologies of GIS concepts, Clodoveu (2005) also elaborates on a situation where part of a GIS team evolved into a research team in cooperation with Universities and research centres. This cooperation raises the ability of the University and sector to focus on the specific data and application needs of the participating organisations. In consequence, this will reasonably lower costs for learning and maintaining the GIT system.

6.3.4 Systematic Research

The Sector ought to adopt systematic research on factors and processes affecting diffusion and utilization of GITs. Impact assessment of GIT initiatives also need to be undertaken. It is quite essential to develop effective frameworks for evaluating the utilisation of GIT. The most reliable way for this is through research. These frameworks are critical to the long-term efficacy of GIT (Eric de man, 2000). This Study proposes the focus of this systematic research to be composed of the vast conceptual and methodological problems that the RIM sector experiences in its GIT initiatives. These initiatives should be spear head by a research and innovations department that could be set up by the line ministry, MoWT.

The investigative programs involving content and process models for GIT impact assessments as presented by Onsrud and Pinto (1991) could be adopted. Content models seek to analyse those specific environmental, organisational and interpersonal factors that have facilitated the process of diffusion and implementation of GITs in this case. In context with GIT for RIM within this Study, these factors may include the visibility of benefits, the opportunity for information sharing among colleagues, the extent of reinvention necessary to adapt to local circumstances, the extent of consensus on methods and standards, the memory of past failures, economic advantage provided by the technology and the presence of backups in case of problems.

Process models on the other hand endeavour to analyse the key steps or decision processes in understanding how GIT innovations are diffused. They are concerned with determining the key phases in the adoption process. Two main sub phases identified are initiation and implementation. At the initiation stage, the organisation becomes aware of the technology and decides to adopt it. At the implementation phase, the organisation engages in the activities necessary to put the technology into practice and incorporate it into existing and developing decision making operations. The goal of the two models is the same, i.e. successful GIT implementation, although the route taken differs, resulting in the need for emphasis of different core issues (Anderson, 1996).

Summed up, systematic research on how GIT implementation tasks have been handled in the sector is needed in order to device corrective means where necessary. New ways for effecting implementation can always be devised if previous methods have not been sufficient but it is important for this to be ascertained through research. The process and content models explained above are just methodological examples on how this systematic research can be effected. Conceptual directives are equally as important and can be expounded. One way of calming down the perceptive digital divide for example, is by conducting research on how best diffusion and implementation of GIT initiatives can be carried out. In this sense, the research should be founded around developing mechanisms of balancing cognition of needs and expectations from GIT within organisations. These efforts that are inclined to institutionalising GITs will go a long way in enhancing capacities of GIT personnel within organisations. The institutionalisation of GIT as proposed by Eric de Man (2000) is a paradigm for studying the role, impact and effectiveness of GIT. In this framework however, institutionalisation of GITs is considered as a capacity building strategy within organisations. This is not to forget that institutionalisation is concerned with the normative existence of GITs in an organisation.

6.4 Establishment of a SDI for Road Maintenance

Sustainable management of the road infrastructure calls for the integration of stakeholders from different decision making levels in planning. For instance, the MoWT makes maintenance decisions of the entire Country's road network at the national level while the contractor's decisions are mainly specific to the roads for which road maintenance contract has been granted. Their data requirements at each level are quite diverse and of different IQL. However, the data requirements for each of the parties feed into each other in some way. For instance, an indication of a damaged road at the level of the ministry will correspond to locations and extents of potholes to be fixed by the contractor on the same road. For harmonisation during monitoring and evaluation, the aims, objectives and choices of either party need to be known. The use of spatial information management tools in form of SDI is efficient in supporting multi stakeholder and multi-level approaches in this road maintenance scenario.

SDIs are a very vital tool in facilitating data sharing as well as jurisdictional cooperation and partnerships. Organisations should therefore start from their corporate knowledge and perspectives. At the corporate level, organisational GIS are adequate for data management. It is from these corporate GIS that organisations should subsequently integrate external views from multi- stakeholder approaches. This integration is envisaged to be helpful in defining problems and setting priority stages of road maintenance tasks. The establishment of a SDI is proposed for the above reasons. SDI initiatives facilitate better management and utilisation of spatial datasets. An 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. The SDI proposed herein is in the sense that it is specific for the RIM sector as the Country subsequently integrates external views into a National SDI. If each of the organisations maintains a corporate

SDI (read GIS) for itself, these can feed into a road maintenance SDI for the entire sector which in the long run would feed into the NSDI for the Country.

Two views have been used to make an understanding of the SDI hierarchy, the umbrella view and the building block view. The umbrella view describes the SDI hierarchy in the sense that the higher level encompasses all the components of SDIs at the lower levels. The building block view asserts that the lower levels of SDI serve as building blocks supporting the provision of spatial data needed by SDIs at higher level in the hierarchy. In this sense, SDI hierarchy creates an environment in which decision makers working at any level can draw on data from other levels depending on the themes, scales, currency and coverage of the data needed (Rajabifard and Williamson, 2001b). The horizontal and vertical arrows in Figure 6-1 illustrate the continuum vertical and complex horizontal relationships between and within the different levels. In SDI initiatives, policy and standard makings are generally based on the umbrella view of SDI which is top-down established. Generating and gathering fundamental datasets on the other hand are based on the building block view of SDI which is founded on the bottom-up approach. Figure 6-1 shows the SDI hierarchy, the foundation for both views; and the intra and inter relationships within and between jurisdiction levels.

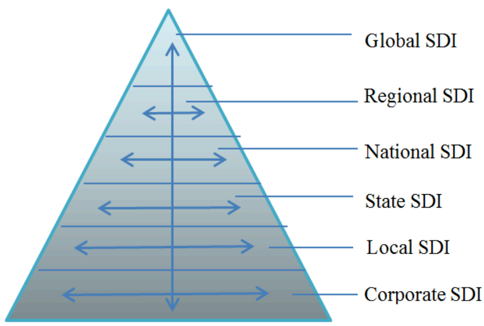

Figure 6-1: The SDI Hierarchy and the Complex Relationships Within and Between the Different Levels of Jurisdiction
Source: Rajabifard and Williamson (2001b) and Rajabifard et al. (2000: 2002)

The existence of a road maintenance SDI is envisaged to boost the establishment of a NSDI. The road maintenance SDI will possess more detailed data which becomes more generalised as one progresses to the NSDI in the hierarchy. This can be explained as follows; the data requirements at the 2 lowest levels of the hierarchy follow directly with the IQL discussed for road maintenance data in Chapter Two (see Figure 2-1). For instance, at the corporate SDI level, IQL-1 data is suffice as it is much more detailed and accurate from which in depth analysis can lead to more generalised data at the higher levels of the hierarchy. The data required at the road maintenance SDI level will be generalised to a certain extent from the corporate SDI thus corresponding to IQL-2 data. The road maintenance SDI in this case characterizes the LSDI in the Figure 6-1. However, beyond the corporate and LSDI levels, discussing IQL data requirements becomes haphazard. The necessity of a LSDI as a building block to a NSDI is emphasized by several authors (Rajabifard et al. (2000), Rajabifard and Williamson (2001a; b), McDougall et al. (2002), Nebert (2004), McDougall et al. (2005a; b), Harvey and Tulloch (2006)). Figure 6-2 shows the 2 views of the SDI hierarchy.

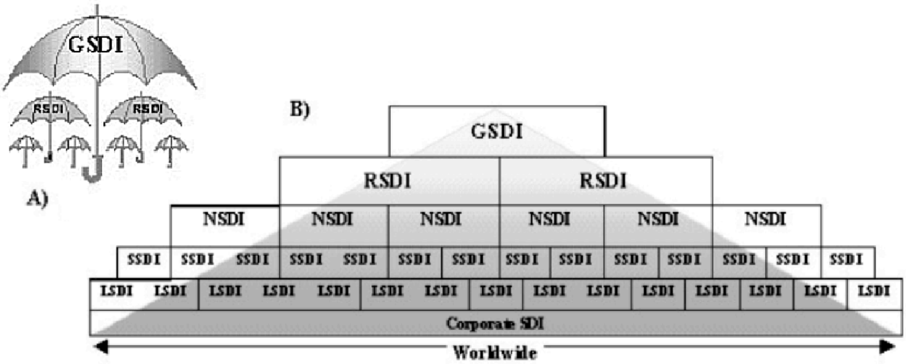

Figure 6-2 (A): The Umbrella View of SDI; 6-2 (B): The Building Block View of SDI
Source: Rajabifard and Williamson (2001a)

To develop a potentially effective SDI, a combined approach of the process and product based SDI development is recommended. The product based represents the main aim of an SDI initiative as linking the existing and potential databases of the respective political and or administrative levels of the community. As noted from the previous chapter, there are a couple of existing datasets that need integration and harmonised use for road maintenance. The process-based model on the other hand presents the main aim of an SDI initiative as defining a framework to facilitate the management and utilisation of information assets. In other words, the objectives behind the design of an SDI by any coordinating agency based on the process-based model are to provide better communication channels for the community for sharing and using data assets, other than aiming toward the linkage of available databases. This Chapter is defining a methodological framework for enhancing GITs in road maintenance. Adopting the process-based model is a step towards enhancing the use of GITs, managing spatial datasets and sharing these technologies. Both models contribute differently to the evolving of the SDI the reason for which a combined approach is recommended.

Recalling Figure 2-7 in Chapter Two, the components of an SDI include people, data, standards, policies and access network all of which require addressing for the sector. Data is the foundation for the SDI and various challenges related to it have been presented under gaps and limitations to GITs within the Study area in Chapter Five. Policies have been addressed as one of the framework components in Section 6.2. Similarly, people are the category for which capacity in form of skills should be built. Standards for the data are equally important for GIS to take effect in an institution. Their purpose is to reduce impediments to interoperability and for this reason; they should be independent from the software technologies used by the organisations. Standards help reduce the costs of sharing data and as well determine the fitness of data for different users. The sector requires standards on many aspects of GI development, processing and use. These include data models, georeferences, spatial data categories, data collection procedures, quality of data sources, data format, database designs, data transfer and use, data accuracy, metadata, and output requirements. For exchange of data amongst organisations, the formats of the data and quality (which can be assessed using metadata) are quite crucial. Besides, establishing formal standards, agreements and coordination structures are necessary preconditions to any distributed GIS (Meredith, 1995).

This Research has addressed data format an aspect of standardisation of datasets in the Sector. In Chapter Seven, a data model has been proposed for the road maintenance sector as a contribution to the standard aspect of the SDI. The use of OpenStreetMap (OSM) is recommended for kick starting the establishment and especially updating of the geometry and topology of spatial datasets. OSM is an editable world street map with an open content license. This data can be downloaded and edited using OSM tools like Merkatoor OSM Editor (MOSME) (MOSME, 2012) and the Java OSM Editor (JOSME) (JOSME, 2012). Unlike Google Maps for example which uses purchased copyrighted map data from established companies and at other times has entered into lease agreement to use copyrighted data, OSM data is freely contributed by data collectors over the globe for free use by any individual or organisation in the production of other usable datasets. In a couple of research projects OSM has been used to generate data for integration with other datasets and to produce more functional products. The quality of this OSM data has been evaluated by researchers' and its use recommended. A context quality analysis of OSM data for Uganda is however postulated. Instances of research on OSM are inclusive and not limited to Haklay and Weber (2008), Blazej et al. (2009), Clinton (2009), Kouandi (2009), Neubauer et al (2009), Girres and Touya (2010), Haklay (2010), Mooney (2010 a; b), and Over et al. (2010). Mapping day Uganda, a project with its activities centred on the global OSM project is actively involved in creating awareness and generating data for the OSM. More details on this project are available on their website (Mappingday, 2012).

6.5 Promotion of Collaboration and Spatial Data Sharing Amongst the Stakeholder Organisations

As cautioned from the previous presentation of the gaps and limitations of GIT use in RIM, and as argued by Anderson (1996) and Eric de Man (2000), GITs encompass technical and non-technical issues. The road maintenance Sector has preferably focussed more on initiatives relating to technical issues without addressing the institutional relations that are a foundation to data sharing. As a result, the technical efforts are not rewarding since its institutional counter parts that facilitate the technical tasks are undermined. Clodoveu (2005) and Clodoveu and Fonseca (2006) argue that when data sharing and cooperation are bound not to occur, the financial and political structure must be much stronger for a GIT based project to succeed. The financial constraint in the sector has been identified and discussed as a limitation to accessing GIT for RIM in Uganda. The political structure addressed in this Study as policy components in favor of GIT use and data sharing has also been ascertained as lacking. This basically means that data sharing and cooperation are bound to occur in RIM. This however is not the case; organisations in RIM are not sharing their geographical data. A policy framework component has been addressed in the earlier section of this Chapter and the financial aspect will likewise be addressed in the succeeding section. Addressing the social aspects that require collaboration between organizations has been argued as equally important as the technical views by a couple of researchers. Anderson (1996) ascertained that it is equally important to realize that success is not necessarily guaranteed by a perfect technical tool. Rajabifard and Williamson, (2001b, p.24) also appreciate social technical emphasis of efforts to ground GIT initiatives. In particular, they guarantee GIS as an underpinning technology for SDI and proceed to argue that "Like any GIS projects, it should also be understood by all spatial data stakeholders that community issues would determine the long run success of a SDI project. SDI, therefore, can no longer be regarded, or taught, primarily as a technical matter. Developing a successful SDI initiative depends at least as much upon issues such as political support within the community, clarifying the business objectives which the SDI is expected to achieve, securing sufficient project funding and enlisting the cooperation of all members of the community, as upon technical issues relating to spatial data quality, standard, software, hardware and networking. Therefore, developing a successful SDI within a political and/or administrative level must be seen as a socio-technical, rather than a purely technical, exercise." As GIS is a foundation for SDIs, the above statement holds for GIS establishments as baseline initiatives for GITs. In promoting organisational cooperation, emphasis should be placed on fostering innovation and transfer of geographic data and technology. This should be accomplished through; constituting partnerships and research networks among;

1. Government agencies,
2. Research and training institutions, and,
3. The private sector.

The above combination of partnerships is known to boost the triple helix phenomenon. As is the aim of the Institute of Triple Helix Innovation[8] , Triple helix involves harnessing and leveraging the complementary expertise of academia, industry and government to facilitate innovation and novel collaborative processes for creative development.

Advocating for international and regional collaboration and cooperation between developed and fellow developing countries is also fundamental in fostering GIT innovations. Traits of such partnerships have been noted in the Sector spear headed by consultancy companies. The government backed organisations are also encouraged to establish such partnerships with which they can benefit and transfer innovations and technologies in GIT. Even though the formulation of such partnerships is envisaged to encourage data sharing, the reverse is also true. Starting with initiatives to share data, healthy and meaningful networks can be generated with broader ideologies of estab-

[8] http://www.triplehelixinstitute.org/?q=node/5

lishing SDI for example. It is important to note that these partnerships and collaboration measures require memoranda of understanding, an issue that has been addressed previously in the policy section. This stresses the proposal that adoption of the strategies identified within the framework should not be addressed in a hierarchical manner but as components that are cyclic and supportive of each other.

The sharing of geographic data and systems facilitates establishment of data partnerships and networks which are the building blocks of SDI. They have also been found to reduce duplication and saving on organisational resources (Nedović-Budić and Pinto, 1999a; b). When establishing data sharing frameworks, such aspects as data ownership (who owns what data? should it be owned anyway?), storage (where and how is the data stored?), access (how will the data be accessed? in form of maps, CDs, internet?) and authority in form of leadership in the sharing framework should be addressed.

6.6 Budgetary Allocation Based on Defined Activities

The availability of funds is quite crucial when talking about success and sustainability of GIT initiatives. This is in affirmation of Ehrensperger et al. (2007) who argue that accessibility, including costs of hardware, software and data are a crucial aspect of successful GIT implementation. Apparently data collection poses the highest costs for which if strategy factors addressing policy, capacity development, SDI and data sharing collaborations are adopted, this will be reduced tremendously. The underlying strategy to handling costs is to prepare annual budgets for data collection and operation of the maintenance management systems. When an organisation's tasks follow a budget based on a conventional maintenance plan, such misleading newspaper reports of failure to utilise allocated funds (Musinguzi, 2011 and Alinange, 2011) will not exist since allocation will in effect be based on the prior passed activity based budgets. However, the initial budgets for new GIT institutionalisation undertaking are quite massive and require additional support from donor funds. When donor funding is acquired, it is advisable that there should be a phased increase in local budgeting to ensure that the road maintenance systems in place become sustainable hence self-funding within a given timeframe. Reference is made to McPherson and Bennett (2005) for some ideas on funding GIT initiatives in road maintenance departments.

For the RIM sector, funding opportunities should be identified by the government and semi-autonomous organisations working aggressively together to pursue application for these funds. The earmarked organisations include the MoWT, URF, KCCA, MoLG and UNRA. Emphasis in utilising these funds should address digital divide issues and framework priorities. For sustainability of funding mechanisms, the usage of GITs should be integrated into the working procedures and hence budgets of all the involved organisations in RIM. Funding of road maintenance in Uganda is undertaken by the URF, a second generation road fund whose revenue is obtained from fuel levies comprised of general revenue taxes and road user charges and managed by boards representing the interests of road users (Gwilliam and Kumar, 2003). However, as concluded by Gwilliam and Kumar (2003), most road funds are still unable to fully fund their desired levels of maintenance because of the residual ministerial control over the level of fuel levy. In effect, research on funding models for road maintenance is fundamental. This Study proposes the URF, within the confines of its mandate, to coordinate this research undertaking using strategies earmarked under Sections 6.3.3 and 6.3.4. This is envisaged to recommend more feasible approaches other than dependence on donor funding that is equally not sustainable

6.7 Adoption of the Dynseg Data Model

The differences in data requirements for various transport applications necessitate application specific data models, definitions of concepts and representations of transport features and their geometry. The enterprise data model by Dueker and Butler (1998) is intended for use by all transportation agencies. This model has a number of advantages including the ability to readily exchange data, to speak with one voice when expressing the needs of GIS-T users to software vendors, and to better utilise the experiences of other agencies in developing and supporting GIS-T systems. In Uganda however, there are no existing data models used for guidance in data collection and structuring of GIS datasets. Data is collected on demand and some attempts are made to structure it basing on the traditional arc node relational data structure. But, road maintenance systems require more standardised methods for developing priorities and assessing conditions. For example, establishment of consistent sections from the collected data based on the uniformity of the values of the road condition data attributes is a basic requirement. This is because road maintenance decisions are made based on the condition of sections or points along the network. The traditional arc node data structure cannot produce such uniform sections when needed. Therefore, this calls for an extension of this model to incorporate dynseg.

Dynseg is considered a superior analysis strategy within the GIS-T. It 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 analysed on the map (Jelokhani-Niaraki et al., 2009) through computations. It places lengths of road into categories based on the values of data collected and that of neighbouring segments. 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 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 (Kennedy et al., 2000). To realise this, three conditions need to be streamlined, namely; (1) The road network should have a measurement system, (2) Each road should have a unique identifier and (3) Events (Point or lines) along the road should indicate a linear distance from a reference marker point. All these conditions can only be realised if:

1. Reference marker points are established,
2. Linear reference system is defined,
3. Unique identifiers for each road are identified, and

4. Syntax, format, terminology and semantics of data are defined.

An object relational data model for dynseg has been proposed for the RIM sector of Uganda. This model development is a step towards standards establishment for the sector. Details of this model are documented in Chapter Seven of this Thesis.

Table 6-1 is a summary of the presented framework components, some guidelines for their implementation and the proposed lead role organisation.

Table 6-1: Summary of the Framework Components, Strategies &Guidelines and Lead Organisations

Framework Components	Strategies &Guidelines	Lead Organisation
1. Policy	• Data Use, standards, copyright, privacy policies • Institutionalisation • Project driven GIT initiatives • Use of Consultants	MoWT UNRA
2. Capacity Building	• Diffusion of GITs • Continued Professional Development a) Structured b) Unstructured • University Collaborations • Research Priorities • Curriculum development • Systematic research • Effective frameworks for evaluation of GIT efficacy • Research and innovations (R&I) department • Content and process models to assess diffusion mechanisms • Institutionalisation of GIT	Employing organisation and personal initiatives MoWT MoLG
3. Road maintenance SDI	• Start with corporate SDI (Individualistic GIS) for organisations • Product and process based model approaches	MoWT
4. Collaboration and spatial data sharing	• Partnerships and research networks • International collaboration and cooperation between developed and fellow developing countries	MoWT
5. Funding Budgets	• Research on more funding models • Prepare annual budgets for data collection and operation • Integrate GITs in the working procedures and budgets for all the involved organisations in RIM – Activity based budgeting • Address digital divides with budget allocations	URF All core organisations
6. Dynseg Data Model	• Establish reference marker points • Define linear reference system(s) • Identify unique road identifiers for each road • Define syntax, format, semantics and terminology, etc.	Data collectors and Collaborating Researchers

The success of GIT use for road maintenance will fundamentally rely on the well-structured standardised data, skilled and motivated personnel and the technology in place (McPherson and Bennett, 2005). A balance between the three using the strategies discussed above will yield successful GIT use for road maintenance. Figure 6-3 illustrates the defined framework in relationship with these fundamental aspects for successful GIT implementation for road maintenance. In the figure,

Successful GIT in RIM is a function of relevant enacted policies, continuous capacity building, well-structured data, sufficient budget, established road maintenance SDI, formal data sharing and collaboration frameworks.

Data, technology and people are interdependent aspects that cannot stand in isolation. The double ended arrows connecting them indicate this interdependence relationship. Framework components of the budget, data sharing and collaboration, policies, SDI and capacity building are directly applicable to all the three aspects as shown by the arrows from them to all the three aspects. For example, capacity building of personnel is on the use, relevance and prospects of geographic data and technologies. However, the framework strategies dealing with the data model are exclusively applicable to data. The doubled ended arrows between the SDI, policies, and data sharing & collaboration illustrate that those framework components are interrelated in the sense as components of SDI. Diffusion and standards as strategies for capacity building and the data model respectively have been included in Figure 6-3 to illustrate alignment of the framework strategies to the overall components. Their dotted boundary is to single them out.

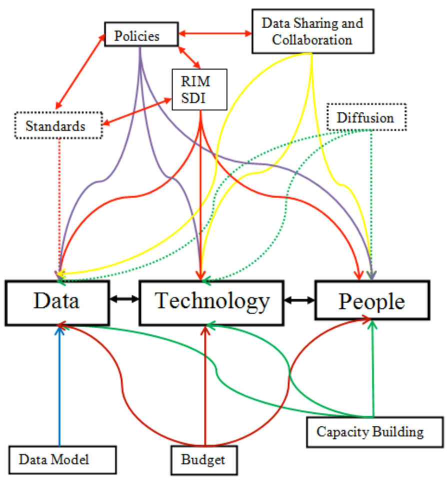

Figure 6-3: Relationship between Aspects for Successful GIT Requirements and the Framework Components

6.8 Conclusion

This Chapter has presented a proposed methodological framework in form of components, strategies and guidelines through which the road maintenance sector would enhance the use of GITs. The standard requirements which comprise GIT success in an institution have been tabled to include - enacted policies that indicate long term commitment by the top management to the GIT projects, sufficient allocation of resources, adequate staffing in terms of numbers and skills, and timely and sufficient training to smoothen the transition to full utilisation all of which have featured as framework components. This framework is not linear in anyway as all strategies discussed are dependent and supportive of each other. Policy, funding and capacity developments however, stand out as most vital and aid in the enforcement of the rest of the defined components. On the adoption of the proposed strategies, it is recommended to develop effective frameworks for evaluating the diffusion and utilisation of GITs. The long term effectiveness of GITs is attributed to these frameworks. With GITs institutionalised in the Sector, the development of customised systems for individual participating organisations will then be possible.

CHAPTER SEVEN
ROAD MAINTENANCE DATA MODEL FOR UGANDA

7.1 Introduction

This Chapter presents the proposed road maintenance data model for Uganda. It gives an overview of the nature of road maintenance data and provides a motivation for the said model. The Chapter presents examples of GIS-T data models and expounds on the modalities of data modelling before explaining the properties that constitute the model. The model has been developed with reference to the enterprise GIS-T data model by Dueker and Butler, and the ArcGIS Transportation Data Model (UN-ETRANS – Unified Network for Transportation) from ESRI, and so, their aspects are discussed within the Chapter. Linear referencing and dynseg as important concepts in referring to road maintenance required locations are expounded. The chapter discusses the proposed conceptual and logical data models and is summarised with a description of the modelled road events and classes.

7.2 Nature of Road Maintenance Data

By road maintenance data this Research refers to road condition data, the basis on which road maintenance decisions are made. This data is both multidimensional and multifaceted. A transportation feature can be multidimensionally referenced as either:

1. One dimensional (1D)-linear reference e.g. kilometer distance from a known point location,
2. Two dimensional (2D) - X, Y planar coordinates,
3. Three dimensional (3D) -X, Y, and Z height information,
4. Four dimensional (4D) - X, Y, Z, and time in case of dynamic objects.

Road maintenance data is also multifaceted in the sense that relationships between transportation features can be defined both physically and logically. Whether physically or logically defined, these features exist both in the real and virtual worlds. The real world is the real world as we speak of it; the world consisting of tangible assets. The virtual world is the database where these data are stored. Complexities in creating transportation databases (models) arise from the fact that there is often a one-to-many relationship between the physical and the logical entities. This means that one physical transportation feature can be logically defined in many ways. The complex properties of transportation networks as being associated with their multimodal nature, having different logical views and 'one-to-many' relationships amongst themselves are affirmed by Miller and Shaw (2001). An illustration of these real, virtual, physical and logical realms is as follows.

The real-physical entities refer to the transportation entities as constructed and used in the real world. Virtual-logical entities relate to data structures such as nodes, links and networks. Virtual-physical entities relate to the geometric and attribute data corresponding to the transportation entity and displayed in the GIS database. These still maintain a one-to-many relationship as many links for example can be represented by a single cartographic line. No wonder Dueker and Butler (2000) define transportation features as likening strings of spaghetti. These various modelling transformations are shown in Table 7-1. Notice that condition attributes are just a broad example of virtual physical data values. The attributes for road condition as presented in Chapter Two are likewise tremendous, including the IRI,SII, skid resistance, PCI, ADT, gravel thickness etc.

Table 7-1: GIS-T Modelling Transformations

	Logical	**Physical**
Real	*Legal Definitions* • Route • National route • District route • Political boundary	*Actual Facilities* • Highways • Roads • Intersections
Virtual	*Data Structures* • Networks • Links • nodes	*Data Values* • Lines • Points • Polygons • *attributes*

Source: Adopted from Fletcher (1987) as cited by Miller and Shaw (2000).

In Uganda, National, District and lower level roads have all got similar characteristics. They are characterised by short sections, many intersections and have no explicit anchor points for location referencing. Anchor points are zero-dimensional well-defined physical object locations in the real world. Roads in Uganda are in consequence similar to urban transportation characteristics as reported by Zhu and Jiang (2009). The information about these roads is quite massive, with multiple attributes and of constantly changing nature. This combined with the multi dimensionality and faceted nature of the described data obviously poses data modelling challenges.

7.3 Motivation for the Proposed Model

An effective road maintenance program requires that road authorities strategically target their investment to those roads that are in the worst condition and that provide most benefits in return (Zvjezdan, 2003). This requires that the condition of roads is continuously evaluated. The most effective way to keep track on the condition of the roads is to have databases which contain the basic indicators that qualify the state of roads. However, even though much of this information is presently not available with the responsible organisations in the Study area, the available lot is archived in databases that are managed in an ad hoc manner. As discussed in the previous chapters, there are a couple of organisations involved in the maintenance of roads. Some of these organisations have developed isolated organisation specific GIS. As prior remarked, due to infrastructure limitations, the Sector is not ready for an enterprise GIS, data still needs to be exchanged among participants. Maintenance decisions are based on indicators derived from related and similar datasets, hence the need for data sharing. This sharing of data limits costly duplication of data collection and management efforts. This necessitates a model in form of a data structure that all organisations can adapt to ease data sharing. Also, in order to make use of the Open GIS Systems, interoperability of transportation data requires common feature schema that is consistent with transportation features (Dueker and Butler, 1999 a; b). Standard data models are known to significantly improve the consistency of asset data records. They assist different organisations in integrating data across various disciplines and to exchange information between various stakeholders (Halfwy et al., 2006). Moreover, data modelling is a contribution to standardisation of datasets.

"The problem with sharing and maintaining GIS-T data among applications like road maintenance is the diversity of formats that lead to inconsistencies, inaccuracies, and duplication in the data." (Dueker and Butler, 2000, p.14) This diversity is due to differences among data structures that make it difficult to achieve consistent information regarding the condition of the transportation network. Moreover, transportation network data structures must be designed to meet the requirements of the analysis to be conducted. The global increasing interest in GIS and ITS have further established the need for structuring road network data. To meet with these advances, transportation agencies need to follow the required basics in designing suitable data models. Goodchild (1998) and Jelokhani-Niaraki et al. (2009) argue that the environment, structure and success of GIS are remarkably dependent on information structure or data modelling. For road maintenance purposes, this guarantees and requires that adequate information about the road network condition is collected and later analysed. The availed data and structures for the organisations involved in this Study have been examined and used in the design of a common and exhaustive data structure (aka model) for road maintenance in Uganda. This Study defines data structure as the arrangement of data in a database.

Most digital transportation databases have been link based which poses a problem for sharing data, a phenomenon that requires agreement on a common base network.

Independent datasets of the same road network from different organisations have been analysed in Chapter Five. It was highlighted how the link node definitions keep changing between datasets. To address issues of interoperability on data exchange, the model adopted in this proposal is a non-link based approach. The topology, geometry and attributes are stand alone. It is non-linked in the sense that the link and node locations on the road are preserved as data exchanged is based on the existing point and line events. Background of the dynseg technique has been used to decide field values for the respective data classes. This is envisaged to allow dynamic segmenting of roads based on condition attribute values of their points and sections.

Within the model therefore, transportation feature(s) along the road(s) are held as object(s) of interest and then the attributes of the point and line events along the feature are located using linear location referencing. This is a requirement for data sharing. It also requires that the geometry of the road remains unchanged while different views of road condition are analysed for maintenance action. The main goal of this proposal is to enable the responsible organisations keep abreast with the maintenance requirements of the overall road infrastructure through sharing event data. Also, to ensure that strategic maintenance decisions are based on well-structured and guaranteed data of required sections or points. This method is envisaged to formulate the best strategies to preserve the overall road network in a desired condition. The proposed model constitutes a data schema for the transport feature (the road), events and their identifiers as these are central for data sharing principles.

7.4 Data Models

The term data model has several definitions. The generic definition is that which defines it as an abstraction of the real world. This abstraction represents data and its attributes, relationships, and a set of guiding rules. A data model can also be defined as a collection of conceptual tools for describing data, data relationships, data semantics, and the data constraints (Dodge and Alesheikh, 2005). It is any structured set of data items, relations, or representation of data (Curtin et al., 2003). Curtin et al.'s (2003) definition of a data model is the basis for the road maintenance data model presented in this Chapter.

Data modelling is a continuous process. For projects for example, data models can be designed at the start and also at multiple phases of the project. Data models are progressive and as such, there is no such thing as the final data model for an application. They are instead considered living documents that change in response to applications. This change however should be backward compatible predetermined by the continuous process of assessing user requirements. Ideally, data models should be stored in a repository so that they can be retrieved, expanded and edited over time. The data model proposed herein is thus not a static structure. More entities and events can be added to the model as road maintenance broadens in scope and stakeholder involvement.

7.4.1 Data Models in GIS

Regardless of the GIS installed in an organisation, three fundamental dataset types often exist. These include a set of feature classes, a number of attribute tables and sometimes, a set of imagery also called raster datasets. Feature classes are much like a folder containing ESRI shapefiles. A shapefile is a popular geospatial vector data format for GIS software. It is developed and regulated by ESRI as a (mostly) open specification for data interoperability among ESRI and other software products. The attribute tables can be either as Excel spread sheets, Database Management Systems (DBMS) e.g. dBase files and Microsoft Access tables, etc.,

Figure 7-1 shows the ESRI geodatabase elements explained.

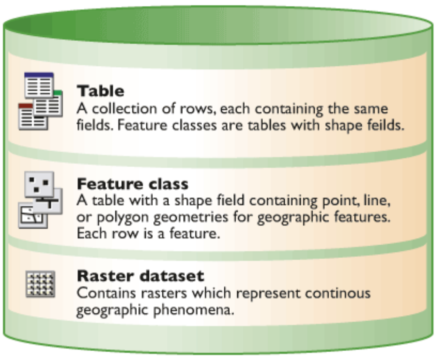

Figure 7-1: Geodatabase Elements Source: ESRI, (2008)

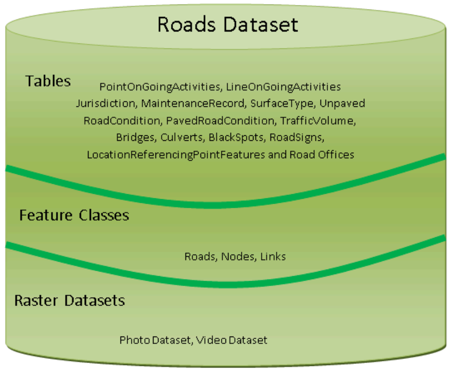

Figure 7-2: Geodatabase Elements of the Proposed Model

A geodatabase is a spatial database designed to store, query, and manipulate GI and spatial data of low dimensionality. Because ESRI is the largest provider of GIS software today, the model presented herein has adopted this basic geodatabase format from ESRI. It has the nodes, links and roads as the feature datasets which together with the roadway inventory data as events form the foundation of the data model.

The tables construct the majority in the data model, with a number of them indicating road event attributes. Besides attribute condition tables, others include; maintenance records, surface types, traffic volume and the Point and Line on going activities. In the GIS software, all these database elements are portrayed as tables; the type of table is the concern of the database administrator and the network analyst. In the proposed model, the photo and video datasets are also presented in tables containing links to their locational directories.

A feature class is essentially a table with a special field that stores its shape (i.e., geometry). Each feature in a feature class shares a common geometry type which can be point, multipoint, polyline, or polygon. For linear features, the geometry type is polyline. A polyline is an ordered collection of paths that can be connected or disjointed. Each path is defined by a series of segments defined by x,y coordinate pairs. Optional measure (m) and elevation (z) values can be stored with any geometry in the geodatabase model so that a feature's geometry may be composed of x,y,m or x,y,z,m (for multipoint features)values rather than just x and y values. In this model, all features have m values assigned to allow their locations on the route geometry to be defined dynamically. Bridges, black spots and culverts for example can be either points or lines depending on how the data corresponding to their location has been collected. This flexibility is left to the organisation mandated to collect these data. Figure 7-2 shows the geodatabase elements of the proposed model. In the model, only the nodes, links and the road have been assigned geometry. The rest of the features have been modelled as events on the road network and hence appear as tables.

The raster datasets are the photo and video datasets discussed in Chapter Five. In the proposed model, the photo and video datasets are also presented in tables containing links to their locational directories.

7.4.2 GIS-T Data Models

Several GIS-T data models have evolved overtime with three broad grouping - network, process, and object models. Network models as the name suggests are those concerned with the topology of connections and intersections of nodes and links of a transportation system. The most referred example of the network model is the Topologically Integrated Geographic Encoding and Referencing (TIGER) files. This model developed from an earlier network data model, the Dual Independent Map Encoding (DIME) system and is accepted by the U.S. Bureau of the Census mainly because of its adherence to the principle of planar enforcement.

Planar enforcement simply means that all lines in a network are forced into a single plane, and that all intersections of these lines are defined in that plane. This means that the polygons that have transportation features as their boundaries become objects of interest in the transportation network which is often not necessarily the case. This is one of the dilemmas with planar enforcement. It is the transportation features not the bounded features that are of interest. Also, the planar enforcement that was needed to generate polygons had the effect of splitting transportation features into many small segments whenever any two features crossed in the plane. In effect, there arise many intersections in the network data structure that do not correspond to the actual intersections in the transportation network (ESRI, 2001). This in consequence leads to data redundancy and necessitates more storage capacity.

Process models are concerned with how transportation activities are conducted. They organise several transportation elements into a model. This model type defines a process by which some transportation planning or maintenance activity takes place. The most widely known transportation process model is the Urban Transportation Planning System (UTPS). It is also known as the 4-step travel demand model owing to the 4 standard model features of trip generation, trip distribution, network assignment and mode choice. This model basically forecasts the demand for transportation resources under different conditions. For application developers who must implement such models, the requirement is that transport elements must be able to be associated/ interoperable) so as to satisfy their needs.

The third category of GIS-T models is the object model. The object model seeks to identify and logically organize many transportation objects in such a way that they can be used for various purposes at hand. Developed in Europe, the Geographic Data Files (GDF) that seek to describe road and road related data is a good example of an object model. It specifies topological relationships and has several levels of description for different representations of objects (ESRI, 2001). The model presented in this Chapter is an object data model for road maintenance in Uganda. It is defined based on the data requirements and roles of the stakeholders in road maintenance. The model has integrated object extracts from various data models used in the transport industry which are relevant to road maintenance in Uganda. This Study has earmarked data modelling as essential in identifying and organising these objects in order to place geospatial products into context.

7.4.3 The Unified Modelling Language (UML)

UML is an industry-standardized general modelling Language. It is a graphical language for visualizing, specifying, constructing, and documenting systems. Its use in this Thesis is for initial structuring of transport data. It has also been used in depicting the use case diagram presented in Chapter Five (see Figure 5-1). The UML standard was created and is managed by the Object Management Group (OMG). It consists of a set of graphic notation techniques that are used to create visual models. UML is extensible and its models may be automatically transformed to other representations by programming languages like Java.

ESRI's ArcGIS software provides the capability for logical data models in UML to be directly transferred into an object relational model named geodatabase using CASE tools (ESRI, 2001). UML was selected for presenting the logical model because of its means to share their schema and rules. Even though GIS software like ArcGIS has other mechanisms that can support schema documentation and sharing, such as via geodatabase XML, the involved organisations are presently not advanced in geodatabase management. Much of the data is stored in relational databases that are easier to manipulate for results. 'UML is one of a number of methodologies that can be used effectively for relational and tabular modelling. It is not a replacement for the necessary work of geographic data modelling required in GIS like defining spatial behaviours and use cases of the spatial relationships you want your geodatabase to convey'(ESRI, 2008). Other methodologies include the entity-relationship modelling that has been used for the conceptual data model.

7.4.4 ArcGIS Transportation Data Model (UNETRANS)

The ArcGIS transportation data model is the basic framework from which the road maintenance model has been derived. It is also commonly known as the UNETRANS (Unified Network for Transportation) data model. The model was designed by ESRI to help in the development of transport applications by providing a context within which a transportation system can be described and assist in the development of a geodatabase. It was designed as an essential data model intended to be used by a broad range of users across the spectrum of the transportation community. It has a primary focus on the needs of organisations that manage road transport networks. One of the potential applications of the UNETRANS data model named by the developers is a pavement management operation that should keep an inventory of the road network. The model endeavours to identify and organise the wide range of the transportation related objects that are essential for advanced transportation planning and management tasks. It contains a couple of packages with several feature classes, object classes, domains and relationships. These packages are basically a set of logical groupings each of which contains a set of objects and feature classes and the relationships between those classes. Figure 7-3 shows an overview of the UNETRANS packages.

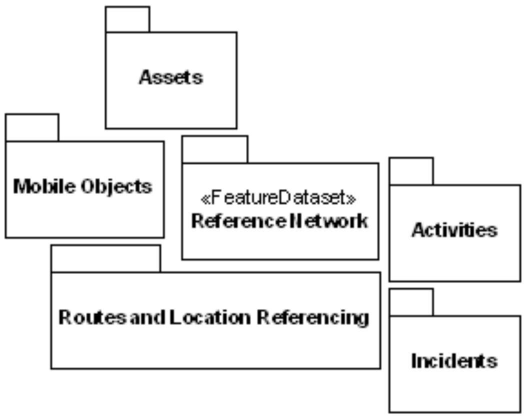

Figure 7-3: UNETRANS Packages Overview
Source: Curtin et al. (2003)

Each object class within a package consists of a set of a descriptive name and attributes that define that object. As the behaviours of these objects are optional, they are not attended to in the developed road maintenance model. To distinguish them from features with explicit spatial representations, the content attributes of the tables are often grouped and referred to as object classes. Each feature class represents a table of information in the geodatabase and is represented by a single class box in the model diagram.

As a starting point for application development, an analysis diagram presenting the essential transportation objects and features in an easy to read form is a requirement. In this Thesis, the conceptual data model is used as the analysis diagram. This conceptual data model gives an overview of the objects available and helps in deciding on which to use, add, delete and modify. The presentation of the logical model in form of the UML is adopted from the UNETRANS data model. UML diagrams give additional information about attributes, relationships between objects and logical groupings of the objects. The advantage with UML is its usability to create an empty geodatabase schema of the model in ArcCatalog. Additional reference to the UNETRANS model is referred to Curtin (2001) and Curtin et al. (2003).

7.5 Linear Referencing System

The linear referencing system of a road is the foundation to the location and analysis of events on the road network using dynseg. Linear referencing in this sense is the most efficient way of managing road maintenance data in a GIS. Most transport agencies are known to use implicitly defined linear LRS datum where the origin and path are specified but not accurately measured. This is the position with the Study area in this Research. The datum, being the framework within which a location is specified, requires guidance for its establishment. This is considered paramount before aspects of the database design are described. In the RIM sector of Uganda, the start and end locations of the roads are implicitly known by the involved organisations. A few core organisations can almost explicitly define the beginning and end points of the roads. Otherwise, since the roads run from and to well-known towns, the centre point of the road at those towns is often regarded as the anchor point. However, Dueker and Butler (2000) urge that an explicit datum must be established to provide the temporal and spatial measurement consistency required for reliable data exchange. An explicit datum should consist of a network of anchor points and anchor sections. Anchor sections are one dimension logical roadway sections between anchor points. But as previously stated organisations collecting data on the road are using independent and implicit anchor points and sections. Unfortunately these are neither explicitly defined nor documented.

The linear reference recommendation in this proposed model is the continuous chainage from the start to the end of the road. This is noted to have several advantages:

1. Users often know the lengths of the roads in terms of kilometers (and usually also miles) from major towns and cities. This translates directly to chainages. Remember, users are one of the stakeholders identified in the RIM sector. Besides using the road, they indirectly keep account of the road status.
2. Although reference differs for the start of chainage measures (either from the start of the road or each new section), contractors and consultants in the sector are already using chainages in implementing road maintenance works.
3. Additionally, the distance from the starting point of each road is taken as an event measure in the GIS which is a backup measure for the next event measures along the transportation feature.

In the GeoTrans data model by Hardy (2005), multiple linear LRM have been provided for. Each linear LRM has been modelled as a linear event that is dynamically segmented onto the base geometry. This allows for each linear LRM to be maintained independently of each other, but still share the same geometry. The linear LRM event table in that case should therefore contain specific naming and measurement conventions that allow events to be geocoded onto it and references that allow it to be geocoded onto the underlying geometry (Hardy, 2005). Geocoding is the process of locating tabular data onto a map based on the attributes in that tabular data. Figure 7-4 is an illustration of multiple linear reference support described above.

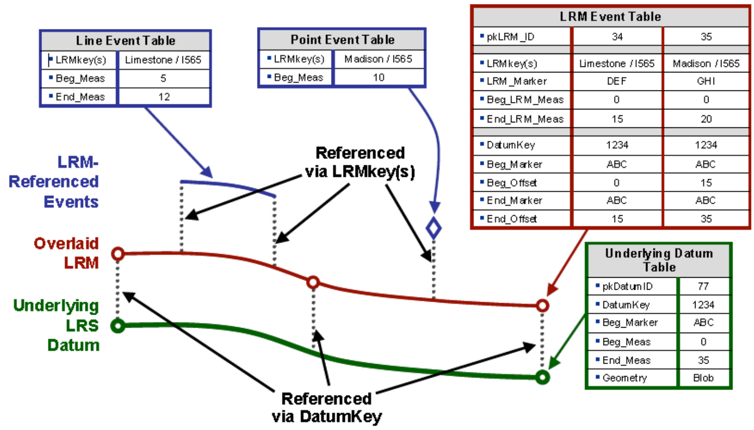

Figure 7-4: Multiple Linear Reference Method Support
Source: Hardy (2005)

Chapter Five has indicated the existence of spatial referencing in databases of road maintenance existing in some organisations within the sector. In those databases, the chainage is stored together with the spatial location either as longitude and latitude or nothings(X) and easting(Y) values. Other than existing as supplementary to linear referencing, this spatial reference has been maintained in the proposed model for two basic reasons.

1. With the advancement of GIT and in this case GPS use, road maintenance departments will in future be well equipped with sets of GPS equipment and continuous collection of this data will accrue. Fortunately, the datum for GPS equipment is worldly defined and therefore exists as default. These data can be roughly estimated while on site to show the exact location of the point and or section in question.

2. Demirel (2002, p. 2) contends that "In GIS-T roads are defined using two-dimensional reference systems. In order to integrate these various dimensions, typically, geographical location by two-dimensional coordinates is used, and linearly referenced road data is considered as attributive data."

By the nature of events on the transportation network, it is often quite handy to report location spatially, this when combined with the linear reference makes location easy to identify in cases of situations like accidents and emerging dangerous potholes. The recommendation for the proposed model however, is that spatial referencing should only be a supplement to the linear counterpart.

In 1962, an objective national highway research program was initiated by officials of the highway administrators of the American Association of State Highway and Transportation (AASHTO). This evolved from the realisation of the increasing complexity of problems to highway authorities. The research program receives full cooperation and support of the Federal Highway Administration of the United States Departments of Transportation (USDOT). It is continually funded by participating member states of the association in employing modern scientific techniques in research activities. The board members are composed of authorities in the highway transportation subject. In particular reference to this Research, a vital contribution of the NCHRP is in the development of a comprehensive model for location referencing that can accommodate and integrate data expressed in one to four dimensions that is a necessity for a wide range of agency applications from facilities management to real-time monitoring. There are up to now three (3), NCHRP 20-27, 20-27(2), and 20-27(3) models whose initiation was in response to the need to provide detailed insights, functional requirements, models, and guidelines for transportation organizations in defining linear referencing systems. Besides multiple linear referencing system capabilities defined previously, multidimensional location referencing has also been tackled. For the latest NCHRP Project 20-27(3) the objectives were to:

1. Establish consensus-based functional requirements for a multidimensional LRS data model for multimodal transportation systems,
2. Develop an improved LRS data model, and
3. Develop guidelines to implement an improved LRS data model in transportation organizations.

Further details of these models are referred to Adams et al. (2001). Reference is also made to Demirel (2002)'s dynamic reference transformation methodology for integrating spatial data with linearly referenced data into a system in three dimensions. The RIM Sector of Uganda is at its infancy to tackle multi-linear and multidimensional location references. However, future models in the sector should make use of the referred models.

7.6 Dynamic Segmentation (Dynseg)

As documented by Kennedy et al. (2000), the usefulness of the road maintenance data can be greatly enhanced by applying a segmentation procedure to produce uniform and consistent sections. Individual organisations in the RIM Sector are using diverse undocumented methods to section and attribute roads. These customized approaches are a limitation to effective data sharing with sister organisations. And yet effective data sharing requires a uniform way of identifying maintenance required points and sections. To achieve this, the necessity of a data model based on user needs of the participating organisations is paramount. The model is envisaged to guide the design of the right database as well as contribute to data sharing standards. It is in this respect that dynseg is earmarked as effective in highlighting these required consistent segments.

Dynseg is a way of referencing linear attribute data on demand, based on a variable segmentation of a single network. It is the process of computing (on the fly) the location of events along a road using linear references. The dynseg process imposes two requirements on the data:

1. A unique identifier and measurement system for each linear feature, the road in this case.
2. A unique identifier and position along a linear feature for each event in an event table.

It is therefore the linear referencing system that allows dynseg capabilities to be implemented on the transportation network. Linear referencing and dynseg together provide the user with the ability to perform spatial analysis. The two also have the capability to promote integration of data from different sources. The combination of the two concepts makes it more convenient to query, display and analyse road attributes. Dynseg allows multiple overlapping of attributes to be stored without duplicating route geometry. The link node structure is preserved while the attribute structure is added above it. The application of dynseg in GIS has a lot of relevance to road infrastructure management referable to the spatially distributed and ever-changing nature of road maintenance data.

Road maintenance data are provided by different organisations responsible for the various roads by jurisdiction. As such, they are collected independently using organisation specific methodologies, and referenced to the road network using different methods (chainages and geographical coordinates in this Study). Since the model proposed in this Study advocates for data sharing among all the stakeholders based on a standard linear referencing method, rigidity in data collection should be emphasised. However, if the multiple linear referencing method support is to be adopted in the future, the use of dynseg concept besides relaxing rigidity on data collection and referencing procedures, sharing of event attribute data will even be more efficiently achieved. As prior mentioned, the Study acknowledges that the process of data modelling is a progressive one involving the assessment of user requirements.

The temporal nature of the road maintenance data warrants flexibility in segment definition. This flexibility is further enhanced with the application of GIS and its ability to accommodate multiple location referencing methods. This flexibility of dynseg, with respect to data collection, management, and integration, was one of the reasons it was adopted for this data model. Hans et al. (1997) confirm that dynseg allows segments to be defined freely without impacting, or being impacted by, other highway attribute data. It is the intention that dynseg provides for a wide array of data analysis and integration possibilities. These possibilities range from simply displaying the locations of pavement management sections, to aggregating or disaggregating, pavement history and condition data in a common table, which is the basis of road maintenance.

Crucial classes of interest in the dynseg model are illustrated using the UML diagram in Figure 7-5.

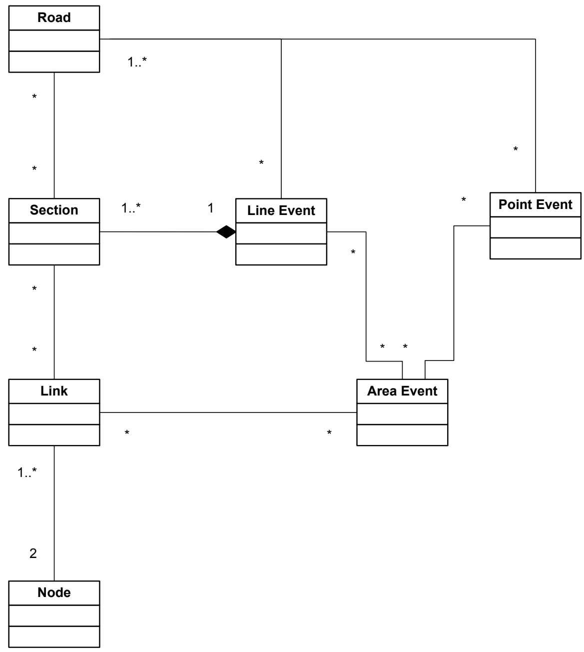

Figure 7-5: A UML Data Model for Dynseg
Source: Adapted from Huang (2003)

This UML data model for dynseg has been adapted from Dueker and Butler (1998) as cited by Huang (2003). In this figure, class diagrams have been used mainly to communicate the structure of the data modelled. Class diagrams are structure diagrams which in UML are used to emphasise the things that must be present in the data that is being modelled. The transportation feature, the point, linear and area events are emphasised. The multiplicity in the model is explained in Table 7-2.

Table 7-2: Multiplicity Explaine

Indicator	Meaning
0..1	Zero or one
1	One only
2	Two only
*	Many
0..*	Zero or many
1..*	One or many

Dueker and Butler (1998)'s model is ascertained to accord with the Ugandan situation. The only deviation is with the terminology 'road' that replaces the 'route'. A route is any linear feature upon which events can be located. It can be a road, railway line, river or airline. In this Research, the road is the route. It is the transportation feature of interest. Roads are assigned road numbers accordingly as would be routes in other countries. For example, the road from Kampala to Jinja is named 'Jinja Road' and its road number is A001. Sections along the road are likewise assigned section numbers from 1, 2 to as many sections as the road could constitute. They translate to a unique identifier of a section e.g. A00101, A00102, etc. In the Ugandan context of road maintenance, road identifiers are based on their jurisdiction. They include the primary (National roads), secondary (District roads) and tertiary (Community Access or Lower level roads). Using dynseg, events can be located along roads because the road feature has an identifier stored in a field and its geometry has a measurement system associated with it. The identifiers for national roads are designated with letter 'A', those for district roads with letter 'B' and those for tertiary or community access roads with letter 'C'.

The node and link are logical terms that indicate point and line connections respectively which make up the transportation feature. In accordance with the model in Figure 7-5, roads are composed of sections. These sections have been defined in order to aid data collection and reference to roads by the responsible management personnel. Sections facilitate effective management of tasks and definitions of project scopes when dealing with maintenance activities. Chainages, the linear reference requirement to effect dynseg, are quite cumbersome to deal with since the roads are quite long. These chainages, when combined with the section numbering, ease reference to a specific location by road maintenance personnel.

However, not much analysis is made of transportation 'area' feature events in the road maintenance sector today. The present GISs in the sector have not considered areal events either. Area events are almost always expressed in the transportation database using a series of points and linear events. This is because majority of GIS are still making use of relational databases where analyses are limited to point and linear events. However, a loop of point and linear events defines area features which are potential area events for future transportation feature analyses. One of the road condition parameter indicators for example is the number of potholes along sections of roads. Majority of erupting potholes are of visible size which can be recorded in terms of dimensions and as such qualifying as area events. Black spots and parking areas share the same concept with potholes as area events. This area event class will be quite relevant in future as advances in GIS analyses are realised in the sector. The framework ArcGIS transportation data model has also for example considered polygonal assets in its assets package. Overall, even though road maintenance data in the RIM sector of Uganda has not emphasised areal events, their future existence cannot be undermined in this data modelling process. The area event class has in effect been maintained in Figure 7-5 for its existence there in does not change any relationship between the modelled feature classes.

7.7 The Proposed Data Models

Three basic stages of data modelling exist which consequently result into the conceptual, logical and physical data models in order of increasing detail. This Research has proposed a conceptual and logical data model for road maintenance in Uganda. The schemas of the tables as should be structured in the physical data model are provided in the logical model. Implementation of the physical data model is however dependent on software choices and additional data that can only be availed by the Sector. As presented in Chapter Five, much of the data is not available today. This aspect of the model development has been reserved for further research. Following is a presentation and discussion of the conceptual and logical data models as proposed.

7.7.1 Proposed Conceptual Data Model

The conceptual data model is the highest level model that portrays real world phenomena of interest in abstract form. At this abstract level, there are no implementation details. What results from conceptual data modelling is a semantic (conceptual) schema. This is a diagram that uses grammar (of the chosen conceptual data model) or notation to capture the aspects of the reality that is being modelled. Only the structure of the information such as data types and their interrelationships are modelled at this stage. Demirel (2002) argues that the success of GIS is highly dependent on information structure analysis and conceptual data modelling.

In reality, there are numerous views that result into conceptual models. Figure 7-6 which shows the levels of data modelling, points to the several views from which a conceptual data model can be taken. The choice of which presentation to use depends on what data is being modelled, the modeller and the audience in other circumstances.

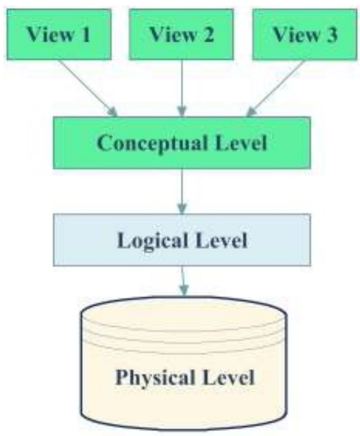

Figure 7-6: Levels of Data Modelling
Source: Elmasri and Navathe (2007)

The view taken in this Research is presented using an Entity Relationship Diagram (ERD). The criterion for use of the ERD was backed by the need to present substantial groups of high level classified entities of the road in a very expressive language. ERD are widespread in the modelling world and easy to read. Figure 7-7 shows the proposed conceptual data model for road maintenance in Uganda. Basically, three groups of entities are modelled - the road's network, point and line events that exist on it. Clearly from the figure these three entities are distinguished.

An integrated top-down and bottom-up approach was used to derive this model. Using the top-down approach, a more detailed description of the model was derived from an overall view of data requirements from the Road Maintenance Sector. The bottom-up approach, on the other hand, considered data requirements of participating organisations hence integrating users' needs as much as possible. This consideration accrued from the concern of the risks of:

1. Missing important detail when using the top-down approach and,
2. Losing the wider view of the RIM Sector when using the bottom up approach.

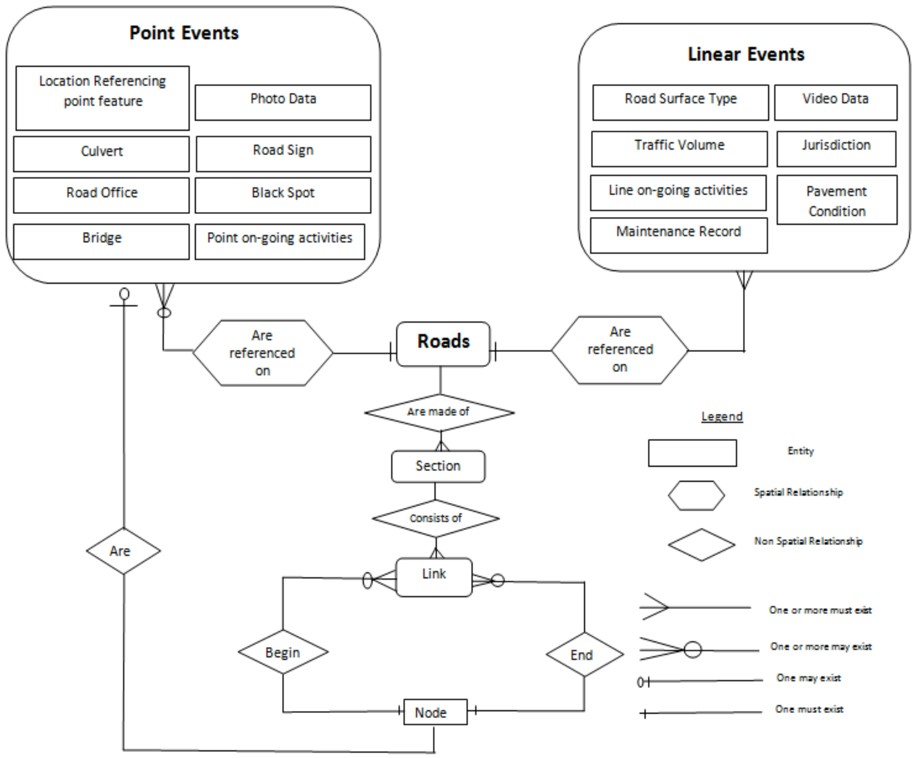

Figure 7-7: Conceptual Data Model - Entity Relationship Diagram
Source: Adapted from Jelokhani-Niaraki et al., (2009)

In this model,

- A node may end or begin one or more links.
- Links are defined by a beginning and ending node.
- Sections consist of one or more links.
- Roads are made of one or more sections.
- A node may be a point event, and one or more point events may be referenced on a road.
- One or more linear events must be referenced on a road.

Besides reference to Jelokhani-Niaraki et al. (2009), this conceptual model was modified with simplification from the enterprise GIS-T data model in Figure 7-8 from Dueker and Butler (1999a; 2000). Dueker and Butler's enterprise GIS-T model was intended as a starting point for application specific transportation databases. The model is not specific for road transportation but all linear transportation networks including, rail and air networks. Even though identified as simplified, the model is quite robust as it includes objects for features on the transportation network, their graphics, the linear referencing objects and logical transformation network elements. The road maintenance model designed is application specific focussing on the road as the transportation feature, events on it and their respective attributes. The conceptions of reference objects being located on the earth using geographic points which are then transformed into cartographic points are inferred issues intended for consideration at the implementation stage. The model by Dueker and Butler (2000) is presented herein as information for further conception of the proposed model.

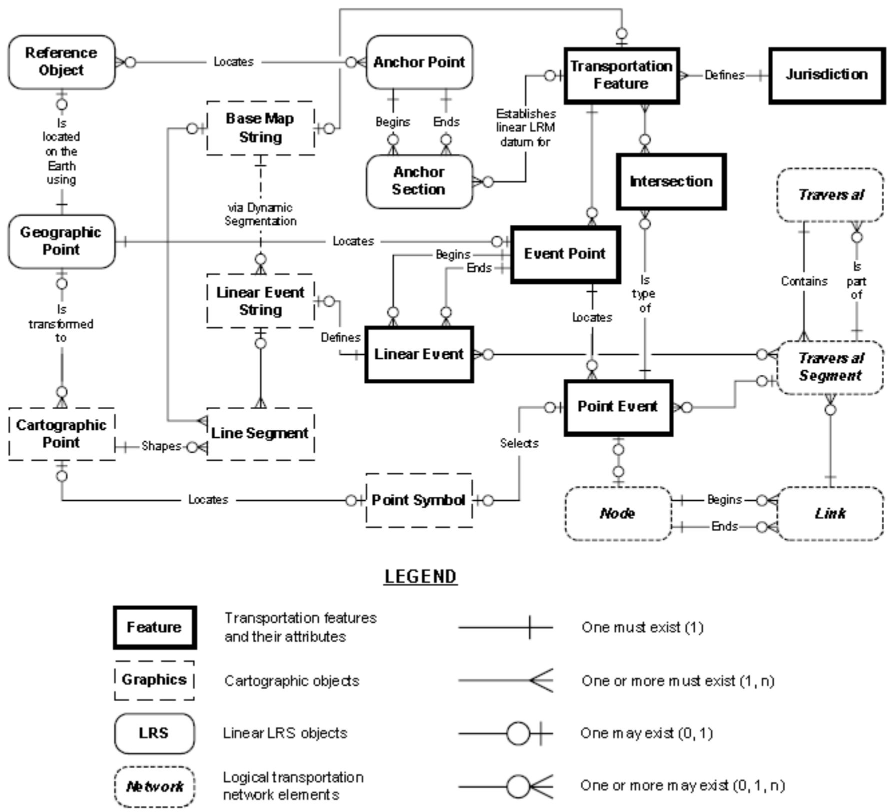

Figure 7-8: Simplified Enterprise GIS-T Data Model
Source: Dueker and Butler (2000)

It is however important to acknowledge, that most of the geodetic control network of Uganda was established by 1960. This is the framework on which the datum of the Country is based. This network of control points consisted of primary, secondary and tertiary points that were distributed throughout the Country. The order of accuracy of these points decreases from primary to tertiary. The computation of this network was originally carried out on the Clarke 1858 ellipsoid using the triangulation chain along the arc of the 30th meridian as control (Okia and Kitaka, 2003). A re-computation of this triangulation network was carried out on the Clarke 1880 ellipsoid in 1960 leading to the naming of the Ugandan datum as the '1960 arc datum' (ibid). The reference geodetic system is now officially called New Arc Datum 1960, and the associated ellipsoid is Clarke 1880 (modified) (IGN, 2003).

In totality, 1,730 control points were established, 130 primary control points 650 secondary control points and 950 tertiary control points. The primary control points were spaced between 30 km to 80 km, secondary spaced between 20 km to 50 km and tertiary spaced between 5 km to 10 km (Okia and Kitaka, 2003). Most of the markers of these controls were however destroyed between the 1970's to 1980's during the period of political struggle. It is currently estimated that of the original control points, there exists only approximately 50 cross-cuts on hard rock and concrete slabs including 14 primary, 27 secondary and 8 tertiary control points (IGN, 2003). These are now the points used in establishing anchor points and sections for the transportation network. This partly explains the gaps relating to accuracies in the database analysis in Chapter Five. It is these national geographic reference points that aid the location of the beginning and ending event points of the road. It is not necessarily only these geographic points that compose the anchor points and therefore segments, but also other reference points as defined through field surveys by the individual transportation departments. This further explains the reduced road mapping accuracies previously highlighted. Geographic points as defined by Dueker and Butler (2000) are zero dimension objects carrying the real world location of the reference object. This is clearly implied in the relationship between geographic point, reference object and anchor point in Figure 7-8.

Dueker and Butler's (2000) enterprise data model was used as the other foundations for the conceptual data model based on its documentation and explicit requirements for transportation feature identification. Reference is made to Kayondo et al. (2011a) where a review of various models and standards in a bid to derive the most suitable data model for road maintenance in Uganda is provided.

7.7.2 Proposed Logical Data Model

The Study has considered an object relational data model. A logical data model translates the conceptual data model into sets of constructs in a DBMS. These constructs are in terms of entities and relationships. The model describes the structure of a database that will be processed by the DBMS. The hybrid object relational data model is intended to balance between the combined advantages using objects and methods concepts from the object oriented model and of relations of the entity relationship models. Relational data models have superiority in effecting standard queries using the Standard Query Language (SQL). Additionally, they accommodate database versioning, are secure, widespread and mature on the market.

Object oriented modelling on the other hand allows for the generation of complex objects with user defined data types based on defined business rules. With an object oriented database, the amount of data in the GIS database component is quite large compared with other systems. This is envisaged to make the system performance low.

The recommendation of a combined object relational data model to benefit from the relational database technology that can be available across a variety of platforms was fundamental. Additionally, object oriented data modelling offers advantages of enhanced abstraction concepts, simplicity in interfacing with other data sources and providing solutions for generalised problems. Within the object relational data model, complex data structures can be stored using the concepts of entity relationships in relational data models. In effect, the model is strong in performing queries of complex structured data. These model types are quite handy in GIS because of their searching capabilities, multi user support and handling complex data. And since majority of the existing databases are relational, and yet object oriented data modelling possess superior advantages of providing solutions to identified problem areas which is key in this model, a hybrid object relational data model was considered for the Sector. This model type has enhanced spatial query opportunities that can be easily performed since the complex objects are stored in tables each with their object identifiers. A comparison of the 3 database models is made in Table 7-3.

Table 7-3: Comparison of Object Oriented, Relational and Object Relational GIS-T Databas

Comparison Parameter	Object Oriented	Relational	Object-Relational
Data extraction	Messaging between objects	SQL- (Structured Query Language)	Complex SQL - Queries complex structured data
Versioning	No- Versioning	Yes-Versioning	Yes- Versioning
Entities	Non atomic (complex) entities	Atomic(simple) entities	Substantially complex entities
Business rules	Integration of business rules with spatial information	Weak support in business rules integration	Business rules integratable with spatial objects
Data types	User defined types and functions	Pre-defined data types	User defined data types and functions
Maturity	Not widespread. Many concepts on test	Mature and wide spread	Least mature and not wide spread (early 1990's)
Size	Sizeable due to non-atomic (complex) entities	Manageable due to atomic entities	**To be managed on implementation**
Performance	Slow due to messaging with large amounts of data	Fast query opportunities	**To be managed on implementation.** Average performance is otherwise envisaged. Slow due to object oriented programing language and fast due to enhanced spatial query opportunities –
Others	Enhanced abstraction concept and encapsulation	Security	Supports abstract data types, procedures, and encapsulation

ESRI provides data model templates for use, extension and adoption to various systems. Besides logically documenting the various classes from the conceptual data model, the ESRI provided template for logical data modelling was used. The resulting model from UML is an object relational data model for road maintenance in Uganda The designed model identifies and codes the attribute types and relationship parameters of objects. It separately emphasises objects having spatial reference, objects without spatial reference and the relationships between them. The objects with spatial references are the feature classes with defined geometry. From the proposed model in Figure 1-9, they are - the Road, Node and Link. Objects with non-spatial reference are those defining the point and line event tables. They are non-spatial in the sense that they are located dynamically on the road transportation feature as point and line events using linear referencing. Their spatial coordinates however may exist as attributes in the respective tables.

This preservation of coordinates as attributes is to cater for such semantics as realignment of the road, corrections in road lengths resulting in more accurate surveys and modifications of topology. This motivation is also backed by challenges related to varied linear referencing methods discussed in Chapter Five and the uncertain reference (anchor) points. The non-spatial objects in the proposed model include; road signs, culverts, bridges, traffic volume, point and line on going activities, Blackspot, road office, linear referencing point features, surface type, maintenance records, jurisdiction, paved and unpaved road condition.

The data model identifies with a total of 19 classes; 'Link', 'Node' and 'Road' as feature classes, 'Bridge', 'Culvert' 'BlackSpot', 'RoadOffice', 'RoadSign', 'PhotoDataset', and 'PointOngoingActivities', as point events, and 'Jurisdiction', 'MaintenanceRecord' 'LineReferencingPointFeature', 'SurfaceType', 'UnpavedRoadCondition', 'PavedRoadCondition', 'VideoDataset', 'TrafficVolume', and 'LineOngoingActivities' as linear events. The 'jurisdiction', 'RoadOffice' and 'MaintenanceRecord' are uniquely referenced directly to the road.

The multiplicity in the model is as explained in Table 7-2. The relationships in the model are defined basing on maintenance standards as follows:

- A linear event may have 1 or 2 'SurfaceTypes'.
- 'PavedRoadCondition' and 'UnpavedRoadCondition' events are sub classes of 'SurfaceType'.
- Depending on the surface type of the road, a linear event may have zero (0) or many paved or unpaved road conditions.
- There may be none or many point and line on going activities on the road.
- A linear event should have only one value for traffic volume assigned.
- A linear or point event may have either none or many video and photo datasets archived.
- Zero (0) or many black spots, bridges, road signs and culverts may exist as events on a road.
- A road is assigned to only one road office.
- Zero (0) or many maintenance records may exist on a road.
- A road exists in only one jurisdiction.

Jurisdiction in the model refers to the territory in which the road is maintained and this dictates the agency in charge. For example, a national road (A001) cannot be a district road at the same time. In reality though, a national road that passes through the district would be identified as a district road for that stretch that belongs to the district. This means that the road A001will be under the management of the national roads and not the district roads.

Figure 7-9: The Proposed Logical Data Model[9]

[9] Even though developed from the ESRI provided UNETRANS data model template as acknowledged in the Thesis, this proposed model is generic and can be adapted by any GIS vendor with Dynseg capabilities.

Logical data modelling was based on some business rules guided by the mandate and objectives of the organisations involved in road maintenance and on the basics of dynamic segmentation analysis. These rules included:

- The events that occur on the transportation system are independent of the geographic datum, cartography and the links and nodes that form the base network. The model emphasises the events occurring on the transportation system.
- The point and linear events on the road as the transportation feature are located using a linear LRS based on a cumulative distance offset, referred to as chainage, from the beginning point of the road.
- Only one linear LRS is used to relate point and linear events to the road.
- All events must be related to the road - i.e., exist on, at, or adjacent to a road. When adjacent and depending on the event, spatial referencing suffices.
- Because of the complexity in implementing many to many (*..*) relationships, they have been avoided in the model
- There are a number of distresses or condition indicators per surface type. And because these indicators are referred to differently between types, 2 different object classes, one for each type have been suggested- paved and unpaved road conditions.

In line with the above business rules and those presented in Section 5.2, the business process in Figure 7-10 has been provided for adopting and using the proposed data model for road maintenance planning.

'Culvert', 'Bridge' and 'BlackSpot' are point events even though some data collection agencies may capture them as linear depending on the type of analyses to be performed on them. The logical data model instances this by maintaining the attributes corresponding to the ToMeasure, ToXCoordinate and ToYCoordinate to the proposed attribute list for cases of when identified as linear events. Similarly, the 'MaintenanceRecord' although part of the linear events, may also record point events.

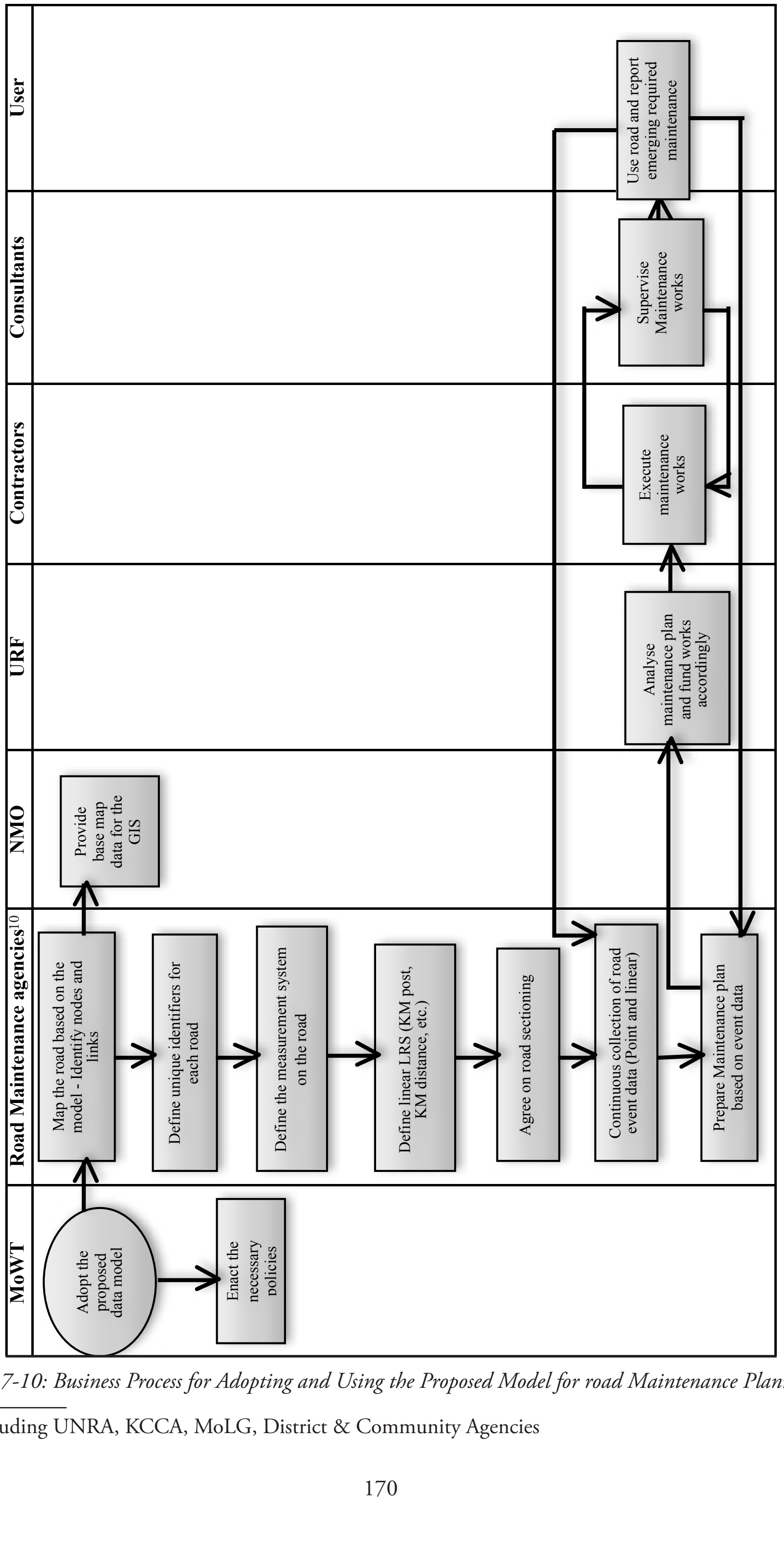

Figure 7-10: Business Process for Adopting and Using the Proposed Model for road Maintenance Planning

[10] Including UNRA, KCCA, MoLG, District & Community Agencies

7.7.2.1 Classes and Attributes Explained

Table 7-4 explains the meaning of the different classes and motivation for their inclusion in the developed model. More detailed meanings of the attributes have been appended to the Thesis (see Appendix 2). The table structure is denormalised since dynseg advocates for denormalised tables as input for display of multiple characteristics (Dueker and Butler, 1998). In contrast to normalisation of datasets, denormalisation requires that there is repetition, redundancy and dependency in datasets. This is important for dynseg since different tables will be independently involved in various analyses hence the need for repetition of fields.

Table 7-4: Model Tables and Motivation Explained

Table	Records stored - Motivation
Road	This is the core dataset (route) structure of the network in consideration. The location and condition of the road network is the foundation for planning of road maintenance activities in the sector.
Jurisdiction	The jurisdiction is the context of the road structure. It's the legal entity in which the roads are defined. The subdivision of the transportation network of the Country. At present, roads in the Country are grouped into National or Primary, District or Secondary and Community Access or Tertiary roads. This table has been created to allow tracking of roads in the different jurisdiction for maintenance planning and in cases of upgrading and rehabilitation.
MaintenanceRecords	The essence of the data model is to effectively manage maintenance in the Country. The maintenance records table indicates which maintenance projects are on-going, the responsible agencies, project timelines, and the costs involved. Data records in this table will be provided by URF
SurfaceType	For maintenance purposes, it is important to know whether a road is paved or unpaved as the condition indicators vary between surface types. There are basically two road surface types; the sealed (paved) and unsealed (unpaved). Both surface types may exist on the same road although at different sections along it.
UnpavedRoadCondition	Stores condition indicators for the unpaved roads
PavedRoadCondition	Stores condition indicators for the paved roads
Traffic Volume	The traffic volume along the road is directly related to the deterioration rate of the road. The average annual daily traffic (AADT) value of the road or section is therefore important to access the importance of the road basing on its usability. The AADT of the road gives an indication on its upgradeability from one jurisdiction e.g. national, to another, e.g. district.

Table	Records stored - Motivation
PhotoDataset	Geo tagged photographs taken with GPS equipped camera to report emergent conditions for urgent maintenance actions have been included as independent datasets. Presently, ordinary pictures are used for road inventory purposes. With GPS coordinates attached to the picture, its dynamic reference to the road is made easier for the decision maker. These photos are to be archived in the directory and probably visualised in independent freeware as illustrated with Geosetter in Chapter Five
VideoDataset	Similarly as with the photo dataset, the video datasets captured during road inventory are to be archived in a directory based on the Jurisdiction and road over which the video was captured.
LineOnGoingActivities	There are road works taking place all through the year, either along sections or at specific locations of the road. These works need to be monitored by the responsible agencies. Information relating to the type, extent and timelines of those projects needs to be recognized and monitored. When at road sections, LineOnGoingActivities are named and when at specific locations, PointOnGoingActivities are named.
PointOnGoingActivities	
BlackSpot	Black spots are those locations along the road that are susceptible to accidents. They should be clearly documented since in many cases are maintenance required zones. These can be either at specific locations or sections qualifying as points or linear events respectively.
Bridge	RIM is inclusive of the maintenance of bridges and culverts. Their locations, condition and other details are important for maintenance decision making.
Culvert	
RoadOffice	Although not necessarily located on the road, locations for the offices accommodating road agencies are important when physical consultations are required from them. Their staff and equipment in custody are important details to monitor.
RoadSign	There are a number of road signs along the roads which give direction to users and also are of good reference as control to data collection in the sector. Their location along the road is useful in referencing roads. Management of these signs is equally important.
LocationReferencePoint Features	These features are often inclusive of anchor points used in establishment of the road datum. Their relevance to the model is to keep reference to location. They are potential features for use in establishing multi linear referencing datum for the future.

The attributes in Table 7-5 need extra clearance and differentiation. The dates are a requirement for purposes of analysing temporal events. They promote temporal persistence to allow for temporal queries.

Table 7-5: Definition of Some Attribute Fields

Attribute	Description
DateRecord:	The date that the data in the table was entered. This date should communicate the currency of the data. Data is not often entered the same day it was collected. The data collection date is most suitable for this attribute. For video and photo datasets for example, this date should principally indicate the date that the video or photographs were captured.
StartDate:	This date corresponds to the start date of the maintenance activity
EndDate:	This date corresponds to the end date of the maintenance activity. For on-going activities for instance, this date can always remain null if it is not known when an activity will end.
RoadClass:	The class of the road. There are three defined road classes, 1st, 2nd and 3rd class in the order of their status. By status is meant the overall condition of the road which combines surface material, condition and comfort to the road user. 1st class roads are made of better material, in good condition and comfortable to the road user.
Comment:	It may at times not be exhaustive to assess a road basing on the indicators as given in the attribute table. More details on any of the attributes in the table may need to be stipulated. An additional comment to this effect is often recommended for emphasis where required.
Direction:	The cardinal and intercardinal directions on the road that the photo or video was captured. For example, North, East, West, South, North West, South East, etc.
Compiler:	The ID of the person that enters the data in the database. In principle, this should be the person accountable for any queries relating to the data. The person who collected the data would be in the best position to be the compiler for accountability purposes.
Directory:	This field specifies the location where the videos or photos for a particular record are stored.
LateralOffset:	Some events may not be located directly on the road and this necessitates reference to their location by an offset distance from the road. This is the distance from the centre of the road at a known chainage to the point in consideration.
RoadSignID:	The identification ID of the road sign. There are a variety of road signs; some are traffic signs, mile posts, kilometer (KM) posts, advertisements, etc. Each of these should have a unique ID and reference to it may assist in the specification of some road locations.
Jurisdiction Description:	The jurisdiction description. There are many districts in the Country today, with probably more still to come. The same applies to municipalities. Counties in different regions may possess similar names. Additional description for the jurisdiction becomes fundamental in such conditions.

Important to note also is that the model has been developed in such a way that more attributes as dimmed necessary can always be added in the various tables. Null values are similarly allowed in situations where the organisation entering given data has no need for certain attributes, and have in effect not assessed them from the field.

CHAPTER EIGHT
CONCLUSIONS, RECOMMENDATIONS AND FURTHER RESEARCH

8.1 Introduction

This Study set out to develop a framework within which the use of GITs can be enhanced for RIM in Uganda. Specifically, the gaps and limitations faced by GIT initiatives for RIM were examined, a methodological framework for accentuation of GITs use in RIM was proposed together with a Geographical Information Systems for Transportation data model for road maintenance in Uganda. A number of research methods were employed in the investigation from which results have been detailed in the previous chapters. In relation to the objectives and research questions as set out in Chapter One, this Chapter summarises the main conclusions and recommendations from the investigations. These conclusions and recommendations are based on the expertise gained from the prolonged interaction with the stakeholders in road maintenance in Uganda, conference presentations and discussions, and the systematic study involving review of documents and field experiments. The Chapter additionally gives the Study's contribution to the GIT body of knowledge and practicalities in the road maintenance Sector. It concludes with recommendations for the Sector and suggestions for further research.

8.2 Conclusions

The conclusions as drawn from various aspects of the Study are presented in conformity with the research questions documented in Chapter One. These include actors/

stakeholders in road maintenance and the gaps & limitations in GIT use for road maintenance, potential and opportunities of GITs in RIM, framework components and strategies for enhancing road maintenance in RIM, the nature of road maintenance data & how effectively this data can be managed in a GIS and the most suitable data model for road maintenance in Uganda.

8.2.1 Stakeholders in Road Maintenance and Gaps & Limitations in GIT use for Road Infrastructure Maintenance in Uganda

In Chapter Five, Section 5.2, the Study established the actors in RIM to include both core and non-core categories. The core stakeholders are those directly involved in road maintenance decision making. They include the UNRA, district & urban council agencies, Consultant and Contractor companies. The non-core or other category is those whose role in road maintenance activities is of indirect nature. This non-core category which includes donors, the user and National Mapping Organisations participates through funding and provision of relevant foundation data for road maintenance decision support.

The Study revealed a number of gaps and limitations faced by initiatives in the use of GITs for RIM. These gaps affirm the assertion by a number of researchers that GIT initiatives have focussed on technical aspects of the technologies at the expense of social and data related concerns, which are the drivers of the former. The gaps which in this Research are effects from the limitations/causes are presented and discussed in Chapter Five, Sections 5.3.2 - 5.3.5

Data sharing and collaboration in GIT initiatives is known to reduce costs and efforts in duplication of tasks. For the RIM Sector, this gap is explained by a number of rationalities as presented in Section 5.3.4 parts (A) - (H).

The backbone to limited usability of GITs in the Sector has featured as absence seizure of a policy component in favour of GIT under the draft national ICT policy. The Research has endeavoured to explicate how all the other gaps and limitations arouse from lack of commitment from the political authorities on the use of GITs in the Country. It has also been argued that, in the long run, GITs, if institutionalised, would themselves be used in routine support of policy making. This is pragmatic given their advantages in facilitation of informed decision making. Details of the noted limitations are explained in Chapter Five, Sections 5.3.6 - 5.3.11

8.2.2 Potential and Opportunities of GITs in RIM

The Study has in Chapter Five, Sections 5.4 (5.4.1-5.4.5) revealed a couple of GIT potentials and opportunities anticipated within the Sector. The summarised potentialities experimented within this Study are just a pointer to the Sector and future researchers on the developing availability of GIT equipment ready to use both within the Sector and for research purposes. They are an advocate for Research and Development (R&D), and Science, Technology and Innovation (STI).

8.2.3 Framework Components and Strategies to Enhance GITs for RIM

In Chapter Six, the Research has chronologically proposed a methodological framework intended to enhance the use of GITs for RIM in Uganda. The presentation of the framework components is not necessarily hierarchal as the components are supportive and dependent of each other. All the devised strategies are geared at strengthening the functionalities of data, people and technology which are key components in spatial data use.

The strategies for effecting capacity building in Section 6.3 (6.3.1-6.3.4) are recommended to be applied for bridging the digital divide highlighted in the limitations to accessing GITs in the Sector. Additionally, the establishment of a research and innovations department is identified to gear the systematic research in technological advancements.

Besides the evolvement of the framework components from the identified gaps and limitations based on the principle of causality and the concept of SDI, they additionally build on the factors of successful GIT implementation by Sieber (2000), Onsrud and Pinto (1993), Crosswell (1991) and Budić (1990). The devised components are also well aligned with the requirements for success of GIT use for road maintenance as pointed by McPherson and Bennett, (2005).

On adoption of the devised strategies, continued development of effective frameworks for evaluation of GIT utilization is recommended. These frameworks are foreseen to aid successful GIT initiatives for the future. These frameworks have also been found critical to the long-term efficiency of GITs by Eric de Man, (2000).

Overall, Successful GIT in RIM is a function of relevant enacted policies, continued capacity building, well-structured data, sufficient and activity based budgets, established road maintenance SDI, formal data sharing and collaboration frameworks.

8.2.4 Nature of Road Maintenance Data and its Effective Representation in a GIS

In Chapter Seven, Section 7.2, the Study has revealed that road maintenance data is multi-dimensional, multifaceted, massive and cumbersome to model. The Study has in addition identified linear referencing as the most efficient way of managing road maintenance data in a GIS. It has illustrated the relevance of linear referencing of road condition data which enables dynamic segmentation to be accomplished (see Section 7.5).

8.2.5 Data Model for Road Maintenance in Uganda

Ready availability of geospatial data and analysis tools for decision making is the utmost requirement to faciliate GIT utilisation in RIM. To this effect, Chapter Seven, Section 7.7 presents the proposed GIS-T data model. Both conceptual (Section 7.7.1) and logical (Section 7.7.2) data models are proposed. The logical hybrid object relational data model has been proposed so as to benefit from the advantages of the combined object oriented and relational data model concepts as reviewed in Table 7-3. The physical implementation of the model, besides requiring in depth consideration of software details, also requires data that is not available from the Sector. This aspect of the model has been left for continuation with the research.

8.3 Research Contribution

The contributions from this Research are presented in two broad categories. Those contributions to knowledge within the discipline of GITs and Road Maintenance, and those direct to the Sector since this has been a participatory research process.

8.3.1 Contribution to Knowledge

The Research has contributed knowledge to both the fields of road maintenance and GITs combined. In attempt to contextualise the Research, the Study has provided a critique of a number of researches and projects in line with GIT and road applications. This critique is a contribution to the body of knowledge as a foundation for future researchers.

Based on a couple of GIS-T models developed by other researchers, the Study has developed a conceptual and logical GIS-T data model for road maintenance decision support. Development of data models is a contribution towards standards development for geographical datasets. This model has emphasised linear referencing, which is key in performing spatial analysis using concepts of dynamic segmentation. In this model however, a single linear referencing system is recommended which still requires rigidity in data collection. Reasons to this single reference are attributed to the infancy of the RIM Sector on GIT modelling and implementation aspects.

Additionally, the Research, through the analysis of the collected data in the RIM Sector, has assessed the challenges faced by GIT initiatives in road maintenance, which challenges are not unique to road maintenance per see but cut across all spatial data utilizing applications in the Country. The findings from this Study have affirmed the alignment of GIT initiatives to technical as opposed to organisational and data related concerns, prior witnessed by previous research.

The Research has proposed a methodological framework composed of various components, strategies and guidelines envisaged to enhance GIT use for road maintenance. This framework is based on research findings, theories and concepts from various researchers on successful GIT projects in and beyond road applications. For instance, the concept of diffusion is a grounded capacity building mechanism and together with GIT institutionalisation has been recommended through psychoanalysis.

The results of this Research have been disseminated in academic sectors and workshop within the road maintenance discipline. As a result, five publications in peer reviewed international conference proceedings have been published. Reference to these publications is made throughout this Thesis. Additionally, two manuscripts have been submitted for consideration to two international journals.

In the field of road maintenance, the Research has invoked some potentials and opportunities of GITs for road maintenance. These unearthed potentials and opportunities are pointers to the growing development of GITs for road maintenance. This undertaking has aroused aspects of science technology and innovation both in the academic world and within the Sector. Examples of these potentialities and opportunities are presented in Chapter Five, Section 5.4 (5.4.1 - 5.4.5).

The Research has demonstrated a low cost mobile mapping methodology for preliminary decision making. In this methodology, a map document from which further analysis can be made is available by the end of the survey.

8.3.2 Other Contributions

Sustainable development in Uganda is guided by adherence to the MDGs and the NDP 2010/11-2014/15. This Research was aligned with goal 8 of the MDGs which strives to make available the benefits of new technologies, especially ICT 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 of ICT for sustainable development. Similarly, objective 5 of the NDP of Uganda is to promote science technology and innovation and ICT to enhance competitiveness. This Research, by addressing gaps and limitations in GITs with the proposed framework strategies, is dealing with the low application of science and technology key binding constraints of the NDP.

Apparently, research in the road maintenance Sector is yet to tackle the various ways in which GITs can be used to further their performance as decision support tools. In addition to data model development, this Research has accomplished this. The gaps and limitations that pose challenges to institutionalisation of GIT in RIM have been assessed. This has unearthed the tendency to focus GIT initiatives on technical issues at the expense of data and social relationships guiding the technical aspects of GIT initiatives. Additionally, it has created an awareness of the potential of GITs in RIM through interaction with stakeholders in the Sector and presentation of research findings and progress at the several conferences and workshop. It is appreciated that with even distribution of these sectorial workshops during the research periods, greater stakeholder participatory input to the development of framework strategies would have been achieved. Moreover, further grounded strategy for inclusion of participants into the Study, coupled with flexibility in the sampling frame and size of the interview participants per organisation, would have added more insight to the research findings and evolved framework.

It is clear that enormous amount of funds are required to maintain up to date inventory data on the condition of roads, in order to keep abreast with the right maintenance required decisions. This Research has proposed a low cost GIT based methodology for preliminary RIM decision support. Other than undertaking the normal 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 such sections, that in depth data collection and analysis should proceed.

8.4 Recommendations

The recommendations accruing from this Research are addressed to the road maintenance Sector and as directions for further research.

8.4.1 Road Maintenance Sector

In much of the reviewed literature, GIT initiatives in road maintenance applications have focussed on technical issues such as building systems and developing data models. Fortunately in some of those study areas, the data and organisational concerns were well attended to. This Study has however ascertained that challenges with GIT initiatives in the RIM Sector are predominated by data and organisational/institutional as opposed to technical concerns. It is recommended that data concerns and organisational relationships also be accorded equal attention as the technical aspects of system set ups in order to enhance GIT usage and maximize their benefits for the Sector.

As this Study has been participatory by involving stakeholders in especially developing the methodological framework components and strategies, in the same light, the Sector is recommended to formally involve the public in data collection regarding road condition. This requires the development of innovative strategies e.g. mobile applications through which the public can communicate developing road conditions for corrective road maintenance. This participatory approach to road maintenance is anticipated to reduce data collection expenditures and boost cooperation between the Sector and the public as stakeholders hence satisfying the evolving quadruple helix model of collaboration.

It is additionally recommended that the Sector makes use of the developed model when establishing standards for data and data sharing.

The Research has unearthed a number of GIT products from the various research activities carried out. These products have been generated from readily available off the shelf equipment and have been manipulated using freeware and open source software with embedded Google Maps. The RIM Sector is encouraged to participate in research and development, and to adopt the culture of innovation especially considering the availability of such opportunities that can foster informed decision making. Even though the scope of this Study was GITs for RIM, this aspect of furthering science technology and innovation is attributed to all sectors that deal with spatial decision making. GITs are fast growing technologies from which numerous benefits can be exploited if research and development is promoted in the Sector.

8.4.2 Further Research

The Study has revealed a number of gaps and limitations to GITs in RIM. Even though strategies to attending to these challenges have featured as framework components, the limited scope of the Study did not permit in depth investigations of each individually. Further research on the following aspects of the framework is suggested:

- An elaboration on the diffusion models and scope of diffusion as a capacity building strategy,
- Funding models for GIT initiatives in RIM,
- Quality assessment of Uganda OSM data.

Additionally, the implementation and validation of the physical data model is an aspect that should be pursued further. This requires an analysis of the software, choice of the geodatabase type to be adopted, and accumulation of data to populate the database.

Further exploration with the Kinect for Windows in mapping and estimating pothole sizes for decision support should be investigated. This development is anticipated to reduce uncertainties of road maintenance budgets in reference to pothole fixing.

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APPENDIX 1

Interview Guide

1. What is the role of your organization in road infrastructure maintenance (RIM)?
2. What types of decisions do you have to make as a stakeholder involved in RIM?
3. What data is involved in making these decisions?
4. What is the relevance of the data above? Or specifically,
5. What information products are generated from this data?
6. How is this data collected? Any special techniques used? Any specific reason?
7. What special techniques are used for acquiring digital information in general?
8. What is the frequency of acquisition of each data type (annually, seasonally, special needs)?
9. How is the collection of data coordinated?
10. How is the data updated?
11. In which format is the data collected, stored and used?
12. How automated are the collection techniques used?
13. What equipment is used in collecting these data?
14. What types of GPS do you use?
15. Do you have a GIS for the organization?
16. What is the competence of the staff managing the GIS?
17. Which systems and or software exist in the organisation? What are the purposes of each?
18. What is the required quality of data that you deal with?
19. How is data accuracy and quality controlled in the organisation?
20. Which spatial information is modelled?
21. Do you have a data model or structure for your spatial datasets?
22. How is the data model documented?
23. Which object classes/entities are used?
24. Which layers, features, attributes are being used?
25. How is the existing data combined into the system?
26. Have any data standards been established?
27. Which linear referencing system is used for obtaining road inventory?
28. How topology is modelled?
29. Which database system is used? What are the reasons for choosing this system?
30. How are updates performed?

31. Do you use satellite imagery?
32. How do you acquire this imagery?
33. What challenges do you experience in using GPS, GIS, Satellite imagery, etc?
34. Do you acquire data from other organisations? (mention stakeholder organisations and other GI using organisations)
35. Do you and how do you share data amongst organizations?
36. What challenges do you experience in sharing your data?
37. How is data copyright and security maintained during this process?
38. How far are new techniques used? Give examples such as internet options for distributing data? The use of Google maps?
39. How do you think the use of these GITs can be increased within and beyond your organisation?
40. Request for any reports or documents and existing data sources in digital format, from which further information can be obtained on what has been discussed?

APPENDIX 2

Tables and their attributes explained

Table: Road

RoadNo:	The identification number of the road. This is the primary key for this table.
Jurisdiction ID:	The identification of the Jurisdiction in which the road lies.
RoadName:	The name of the road.
RoadClass:	The class of the road.
PhotoID:	The ID of the Photo dataset of the road.
VideoDataID:	The ID of the Video dataset of the road.
Surface_Type:	The type of surface of the road, either sealed (paved) or unsealed (unpaved).
No.OfSections:	The number of sections on that road.
SectionNo:	The number of the section in consideration.
SpeedLimit:	The speed limit of the road.
Origin:	The origin description of the road.
Destination:	The destination description of the road.
FromMeasure:	The beginning chainage of the road or section.
ToMeasure:	The end chainage of the road or section.
FromXCoordinate:	The X Coordinate of the beginning point.
FromYCoordinate:	The Y Coordinate of the beginning point.
ToXCoordinate:	The X Coordinate of the end point.
ToYCoordinate:	The Y Coordinate of the end point.
DateRecord:	The date that the particular record was entered into the database.
NumberOfLanes:	The number of lanes of the road or section.
Length:	The length of the road or section.
Direction:	The direction of the road or section in consideration.
T_volume:	Average Annual Daily Traffic of the road or section.
AgencyInCharge:	The agency in charge of the road.
Compiler:	The person who entered the records in the database.

Table: Point Event Table

RoadNo:	The identification number of the road. This in combination with the SectionNo is the primary key for this table.
RoadName:	The name of the road.
SectionNo:	The number of the section in consideration.
FromMeasure:	The chainage of the road point.
XCoordinate:	The X Coordinate of the point.
YCoordinate:	The Y Coordinate of the point.

Table: Line Event Table

RoadNo:	The identification number of the road. This in combination with the SectionNo is the primary key for this table.

RoadName: The name of the road.
SectionNo: The number of the section in consideration.

FromMeasure: The beginning chainage of the road section.
ToMeasure: The end chainage of the road section in consideration.
FromXCoordinate: The X Coordinate of the beginning point of the section.
FromYCoordinate: The Y Coordinate of the beginning point of the section.
ToXCoordinate: The X Coordinate of the end point of the section.
ToYCoordinate: The Y Coordinate of the end point of the section.

Table: Jurisdiction
JurisdictionID: The ID of the jurisdiction. The unique identifier of this table.
JurisdictionName: The name of the jurisdiction.
No.Of Roads: The number of roads in that jurisdiction.
JurisdictionDescription: The description of the jurisdiction.
Compiler: The person who entered the records in the database.

Table: SurfaceType
Surface_Type: The type of surface of the road.
DateRecord: The date that the particular record was entered into the database.
Comment: Any more details that may need to be captured about the surface type.
Compiler: The person who entered the records in the database.

Table: PhotoDataset
PhotoID: The ID of the photo dataset, also primary key for the photodataset table.
JurisdictionID: The ID of the jurisdiction in which the photo was taken.
DateRecord: The date that the photograph was taken.
Direction: The Direction in which the photo was taken.
Comment: Any more detail about the photo taken.
Directory: The directory in which the photo is stored.
Compiler: The person who entered the records in the database.

Table: VideoDataset
VideoDataID: The ID of the video dataset, also primary key for the videodataset table.
JurisdictionID: The ID of the jurisdiction in which the video was captured.
DateRecord: The date that the video was captured.
Direction: The Direction in which the video was captured.
Comment: Any more detail about the video captured.
Directory: The directory in which the video is stored.
Compiler: The person who entered the records in the database.

Table: TrafficVolume

T_Volume: The Average Annual Daily Traffic of the road section.
Compiler: The person who entered the records in the database.

Table: MaintenanceRecord

Maintenance ID: The ID of the maintenance activity. This is the unique identifier of this table.
AgencyInCharge: The agency responsible for the identified maintenance.
MaintenanceDescr: The description of the maintenance activity in consideration.
StartDate: The date of commencement of maintenance works.
EndDate: The date of cease of maintenance works.
Maintenance Cost: The cost of the maintenance activity.
DateRecord: The date that the particular record was entered into the database.
Compiler: The person who entered the records in the database.

Table: PointOnGoingActivities

PtActID: The ID of the point activity. The unique identifier of this table.
ActivityDescr: The description of the point activity.
ProjectDescr: The description of the project under which the point activity lies.
StartDate: The start date of the activity.
EndDate: The end date of the activity.
DateRecord: The date that this record was entered into the database
CostActivity: The cost of the activity
LateralOffset: The offset of the point activity from the road.
Comments: Any more comments regarding the activity.
Compiler: The person who entered the records in the database.

Table: LineOnGoingActivities

LineActID: The ID of the line activity. The unique identifier of this table.
ActivityDescr: The description of the linear activity in consideration.
ProjectDescr: The description of the project under which the linear activity lies.
StartDate: The start date of the activity.
EndDate: The end date of the activity.
DateRecord: The date that this record was entered into the database.
CostActivity: The cost of the line on going activity.
LateralOffset: The offset of the line activity from the road.
Comment: Any more comments regarding the activity.
Compiler: The person who entered the records in the database.

Table: RoadOffice

RdOffID: The ID of the road office. The unique identifier of this table.
AgencyInCharge: The agency in charge.
EquipmentType: The type of equipment is custody.
EquipmentNo: The number of equipment of a certain type.

NoOfStaff:	The number staff in the agency.
Compiler:	The person who entered the records in the database.

Table: RoadSign

RoadSignID	The ID number of the road sign. The unique identifier of this ta ble.
Lateral offset	The offset of the road sign from the road.
Roadside:	The side of the road on which the road sign lies.
RoadSignType:	The type of the road sign.
Compiler:	The person who entered the records in the database.

Table: LocationReferencePointFeature

LRPFID:	The location reference point ID. This is the unique identifier of this table.
FeatureDescr:	The description of the Location Reference Point Feature.
RoadSide:	The side of the road where the LRP feature is located.
XOffset:	The X offset of the location of LRP feature.
YOffset:	The Y offset of the location of the LRP feature.
DateRecord:	The date that the record was entered into the database.
LocationDescr:	The description of the location of the LRP feature.
Comment:	Any more comment regarding the LRP feature.
Compiler:	The person who entered the records in the database.

Table: BlackSpot

BSID:	The ID of the Black spot. The unique identifier of this table.
BlackSpotCause:	The cause of the black spot.
BlackSpotSevenity:	The severity of the black spot.
ToMeasure:	The end chainage of the black spot stretch.
ToXCoordinate:	The X Coordinate of the end location of the black spot.
ToYCoordinate:	The Y Coordinate of the end location of the black spot.
DateRecord:	The date that the record was entered into the database.
Comment:	Any more comments regarding the Black spot.
Compiler:	The person who entered the records in the database.

Table: Bridge

BridgeNo:	The reference number of the bridge. The unique identifier for this table.
BridgeName:	The name of the bridge.
BridgeType:	The type of the bridge.
ToMeasure:	The end chainage of a bridge stretch.
ToXCoordinate:	The X Coordinate of the end location of the bridge.
ToYCoordinate:	The Y Coordinate of the end location of the bridge.
BridgeCondition:	The overall condition of the bridge.
LegalLoad:	The legal recommended load of the bridge.
SpeedLimit	The recommended speed limit of the bridge.

BridgeLength:	The length of the bridge.
BridgeWidth:	The width of the bridge.
BridgeHeight:	The height of the bridge.
Comment:	Any more comment regarding the bridge.
Compiler:	The person who entered the records in the database.

Table: Culvert

CulvertID:	The ID of the culvert. The unique identifier for this table.
ToMeasure:	The end chainage of a culvert stretch.
ToXCoordinate:	The X Coordinate of the end location of the culvert.
ToYCoordinate:	The Y Coordinate of the end location of the culvert.
CulvertType:	The type of the culvert.
CulvertCondition	The overall condition of the culvert.
CulvertAlignment	The alignment of the barrels.
CulvertBarrels	The number of barrels contained by the culvert.
CulvertHeight:	The height of the culvert.
CulvertDiameter:	The diameter of the culvert.
CulvertLength:	The length of the culvert.
Comment:	Any more comment regarding the culvert.
Compiler:	The person who entered the records in the database.

Table: PavedRoadCondition

Surface_Type:	The type of material on that section of the carriageway.
Rd_Width:	The width of the carriage way at the section.
Shoulder_Type:	The type of material on the road shoulder at the section.
Shoulder_Width:	The width of the road shoulder at the section.
Edgedrop:	The left, right or Carriageway edge drop.
WidthLoss:	The left, right and Carriageway width loss.
Friction:	The left, right or Carriageway friction cause.
RdFriction:	The left, right or Carriageway friction severity.
Rutting:	The left, right or carriageway rutting.
AllCracks:	The carriageway overall cracks.
WideCracks	The carriageway overall wide cracks.
Ravelling:	The carriageway overall ravelling.
Potholes:	The carriage way overall potholes along the section.
Rutting:	The left, right or carriageway rutting.
DateRecord:	The date that the record was entered into the database.
Comment:	Any more comment on the condition of the road section.
Compiler:	The person who entered the records in the database.

Table: UnPavedRoadCondition

Surface_Type:	The type of material on that section of the carriageway.
CWay_Width:	The width of the carriage way at the section.
Shoulder_Type:	The type of material on the road shoulder at the section.
Shoulder_Width:	The width of the road shoulder at the section.

RdF_Grade:	The road friction severity.
RdF_Type:	The roadside friction cause.
Dr_Formation:	The road drainage formation at the section.
Dr_Condition:	The road drainage condition at the section.
Gr_Thickness:	The carriageway gravel thickness.
Roughness:	The road roughness.
Erosion:	The road erosion gullies.
Corrugation:	The road corrugation.
Potholes:	The number of potholes along the section.
Rutting:	The road rutting.
DateRecord:	The date that the record was entered into the database.
Comment:	Any more comment on the condition of the road section.
Compiler:	The person who entered the records in the database.

APPENDIX 3

MAKERERE UNIVERSITY

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OFFICE OF THE DEPUTY VICE-CHANCELLOR
(Finance & Administration)

Date: 28th October 2010

The Director Safety Security and Economic Regulations
Civil Aviation Authority
Entebbe, Uganda

Dear Sir,

RE: **REQUEST TO CARRY OUT AN AERIAL SURVEY OF ROADS IN KAMPALA AND JINJA DISTRICTS**

We are undertaking a research on applications of Geographical Information Technologies in road infrastructure maintenance in which Ms. Mazzi Lydia Kayondo is a PhD student. Lydia is undertaking a sandwiched PhD program at Makerere University in Uganda and Blekinge Technical Institution (BTH) in Sweden. Her study area covers Kampala and Jinja district.

As part of her research, together with the Swedish supervisor, they have filmed and taken pictures of the sections of roads within her study area with a video camera mounted on a vehicle. Her next stage is to film the same road sections with the camera mounted on an aircraft.

The intention is to develop a cost and time effective mechanism of assessing the condition of roads using geographical information technologies for purposes of prioritizing the road maintenance activities. The field work is planned for the first week of December between 1st and 8th December 2010.

This is to request for a permit to carry out the above aerial survey during the stated times. Attached are pictures and information concerning the paramotor that will be used. The copies of the certificates held by Karl Olsson, the pilot who will do the flying are also attached.

We shall be grateful for a timely positive response.

Yours Sincerely,

MAKERERE UNIVERSITY
28 OCT 2010
FINANCE & ADMINISTRATION
DEPUTY VICE CHANCELLOR

Prof. S.S. Tickodri-Togboa
Ag. Deputy Vice Chancellor (F&A)

MAKERERE UNIVERSITY

P.O. Box 7062 KAMPALA
UGANDA

DEPARTMENT OF SURVEYING

Your Ref. Our Ref.
Date: 22nd Nov. 2010

To: Aircraft Clearance Office
Entebbe International Office
Civil Aviation Authority
Entebbe, Uganda

Re: Request for Clearance to Carry out an Aerial Survey of Roads in Kampala and Jinja Districts

The Department of Surveying in collaboration with Bleinge Technical Institution (BTH) in Sweden is undertaking a research on Applications of Geographical Information Technologies in Road Infrastructure Maintenance. Under this research, Ms. Mazzi Lydia Kayondo is undertaking a sandwiched PhD program at Makerere University in Uganda and Blekinge Technical Institution (BTH) in Sweden. Her study area covers Kampala and Jinja districts.

As part of the research, Lydia, together with Prof. Gerhard Bax, the Swedish Supervisor have already filmed and taken ground-borne images of the sections of roads within the study area using a Global Positioning Systems (GPS) embedded video camera mounted on a vehicle. Their next stage is to film the same road sections with the camera mounted on an air-borne paramotor, which is a light aircraft. The paramotor weighs approx 50kg and will arrive as cargo onboard KLM on 28th Nov. 2010. The overall aim is to develop a cost and time effective mechanism of assessing the condition of roads using geographical information technologies for purposes of prioritizing the road maintenance activities.

The field work is planned for 7 days from 2nd to 9th December 2010. The plan is to fly from Kampala to Jinja following the highway for the first day, and within Jinja, to fly along Kamuli, Iganga and Bujagali roads for the rest of the days. The techniques developed will contribute towards addressing the problem of road maintenance in Uganda.

The purpose of this letter therefore is to seek for clearance from your office. This is a preliquisite for Civil Aviation Authority to grant us permission to fly the aircraft for the purposes of the aerial survey during the stated times.

Attached are pictures and information concerning the paramotor that will be used. The copies of the certificates held by Karl Olsson, the pilot who will do the flying are also attached.

We shall be grateful for a timely positive response.

Yours Sincerely

MAKERERE UNIVERSITY
22 NOV 2010
DEPARTMENT OF SURVEYING

Dr. Moses Musinguzi
Head of Department

School of Planning and
Media Design

Your Ref.

Our Ref.

Date: 24th Nov. 2010

To: The Director
Safety Security and Economic Regulations
Civil Aviation Authority
Entebbe, Uganda

Dear Sir,

Re: Request for Permission to fly paramotor for scientific purposes within Uganda

As a follow up to the earlier submission dated 28th October 2010 (attached), this is to request for permission to fly within Uganda. As mentioned then, we are undertaking research on Applications of Geographical Information Technologies in Road Infrastructure Maintenance in which Ms. Mazzi Lydia Kayondo is undertaking a sandwiched PhD program at Makerere University in Uganda and Blekinge Institute of Technology (BTH) in Sweden. Her study area covers Kampala and Jinja districts.

As part of the research, Lydia, and I, her Swedish Supervisor have already filmed and taken ground-borne images of the sections of roads within the study area using a Global Positioning Systems (GPS) embedded video camera mounted on a vehicle. Our next stage is to film the same road sections with the camera mounted on an air-borne paramotor, which is a light aircraft. The paramotor weighs approx 50kg and will arrive as cargo onboard Ethiopian airways on 28th Nov. 2010 together with the pilot, Mr. Karl Olsson. Paramotors are internationally considered as sports equipment and the different parts are assembled within a few minutes (see http:// www.youtube.com/watch?v=WQdw955PLQk). As sport equipment all insurance and registration is on the pilot and not on the paramotor itself (see http://en.wikipedia.org/wiki/Powered_paragliding).

Figure 1: Picture showing an airborne paramotor similar to the one used in our study.

School of Planning and Media Design
Blekinge Institute of Technology, Address: 374 24 Karlshamn, Telephone: 46 455-38 50 00

Flying paramotor is very safe as pilot and engine stabilize the aircraft. Furthermore the pilot carries an extra safety parachute.

The overall aim of our study is to develop a cost and time effective mechanism of assessing the condition of roads using geographical information technologies for purposes of prioritizing the road maintenance activities.

The field work is planned for 7 days starting from 2nd to 9th December 2010. The plan is to fly from Kampala to Jinja following the highway for the first day, and within Jinja, to fly along Kamuli, Iganga and Bujagali roads for the rest of the days. The techniques developed will contribute towards addressing the problem of road maintenance in Uganda. Attached are pictures and information concerning the paramotor that will be used, a letter granting permission from the Ministry of works, Uganda, a letter from the department showing consent over the research, the pilot's license, which includes both a health and a 3rd party insurance for the pilot and the equipment he is using. Mr. Olsson himself is a steering board member of the Swedish Paragliding Association (**www.paraglyding.se**) and he has also the right in Sweden to inspect a paramotor annual for its air worthiness. He is a paramotor trainer and has several hundred hour of flying time with this sort of equipment. After landing, the paramotor is easily packed in the trunk of a car, and we look forward to demonstrate our paramotor for you, a flight equipment that is hard to explain in terms of traditional aircraft terminology.

As we intend to fly at low altitude with visible contact to the crew in the accompanying vehicle, no special flight radio is required according to international rules. We will, however, carry radio communication devices.

The purpose of this letter therefore is to seek for a flying permit from your office. We shall be grateful for a timely positive response.

Yours Sincerely
Prof. Gerhard Bax

School of Planning and Media Design
Blekinge Institute of Technology, Address: 374 24 Karlshamn, Telephone: 46 455-38 50 00

CIVIL AVIATION AUTHORITY

UGANDA

Head Office Building
Entebbe International Airport
P.O. Box 5536, Kampala, Uganda

Our Ref: DSSER/4043/PRV

Your Ref:

30 November 2010

The Deputy Vice-Chancellor (Finance &Administration)
Makerere University
P. O. Box 7062
KAMPALA

REQUEST TO CARRY OUT AN AERIAL SURVEY OF ROADS IN KAMPALA AND JINJA DISTRICTS

We refer to your application dated 28th October 2010 regarding a request for a permit to carry out aerial survey of the above mentioned roads using an air-borne paramotor—a light aircraft.

Upon evaluating the application, the CAA noted that the paramotor owners have not submitted any evidence to show that paramotor aircraft:

1. is registered in any country as required by regulation 3. (1) of the Civil Aviation (Aircraft Registration and Marking) Regulations, 2006. The regulation provides that a person shall not operate an aircraft, within or fly over Uganda unless the aircraft has been registered in Uganda; a Contracting State to the Convention on International Civil Aviation; or some other State in relation to which there is in force an agreement between the Government of Uganda and the Government of that State; and

2. meets the requirements of regulation 8 of the Civil Aviation (Airworthiness) Regulations, 2006. The regulation prescribes that a person shall not fly an aircraft unless there is in force in respect of that aircraft a certificate of airworthiness or restricted certificate of airworthiness or a special flight permit duly issued or rendered valid under the law of the state of registry.

Please also note that regulation 55 of the Civil Aviation (Aerial Work) Regulations, 2006 prescribes that a person shall not use an aircraft in motion picture, aerial photography or aerial survey operations, unless there is in respect of the aircraft a certificate of airworthiness or a restricted certificate of airworthiness issued for the purpose of exhibition.

In view of the foregoing, I regret to inform you that the CAA is not able to issue the requested permit unless the above stated safety regulatory requirements are fulfilled. Accordingly, the applicants are advised to either submit evidence that their aircraft meets the requirements or use any other suitable aircraft that is compliant with the safety regulations.

Milton Tumusiime
For: DIRECTOR, SAFETY, SECURITY & ECONOMIC REGULATION

CC: The Permanent Secretary, Ministry of Works and Transport

CC: Prof. Gerhard Bax

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