Algorithmic Incorporation of Geographical Information Technologies in Road Infrastructure Maintenance in Uganda

Lydia Mazzi Kayondo¹, Sandy Stevens Tickodri-Togboa², Gerhard Bax³

¹Assistant Lecturer, Department of Surveying, Makerere University, P.O.Box 7062, Kampala, Uganda

Corresponding email: mklydia@tech.mak.ac.ug; Lndandiko@yahoo.co.uk

²Professor, Department of Computer Engineering, Makerere University, P.O.Box 7062, Kampala, Uganda

³ Professor, School of Technoculture, Humanities and Planning, Division of Technoscience Studies, Blekinge Institute of Technology, PO-Box 214, S-374 24 Karlshamn, Sweden

ABSTRACT

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

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

1.0 INTRODUCTION

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

2.0 METHODOLOGY

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

3.0 ROAD MAINTENANCE ACTIVITIES AND ACTORS

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

4.0 ROAD MAINTENANCE DATA

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

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

Table 1: Elements of Road Management data

Source: Paterson and Scullion (1990)

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

5.0 GAPS AND LIMITATIONS IN GIT USAGE IN RIM

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

5.1 Gaps in GIT Utilization

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

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

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

5.1.4 There is lack of a common data foundation to address key national and local maintenance requirements: Initiatives for establishing a Spatial Data Infrastructure (SDI) - a framework for connecting all users of Geographical Information (GI) to the producers (or

data) through an efficient infrastructure (Nebert, 2004) are still not forthcoming in Uganda (Musinguzi *et al.*, 2007).

5.2 Limitations in GIT usage

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

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

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

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

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

6.0 ALGORITHMIC ACCENTUATION OF GIT USAGE IN RIM

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

6.1 Policy on GIT usage for RIM

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

6.2 Capacity building in GITs

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

6.2.1 Continued Professional Development (CPD): CPD should become an integral part of the processes of enhancing geospatial capacity in RIM. Organizations that provide professional training on geographic information sciences such as universities, and private companies should be strengthened. This definitely requires a budget as will be discussed in the section 6.5.

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

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

6.3 Establishment of a LSDI for road maintenance data

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

6.4 Promoting collaboration and data sharing amongst the stakeholder organizations

Like all technologies, GITs encompass technical and non technical issues (Eric de Man, 2000). It is therefore important to realize that success is not necessarily guaranteed by a 246

perfect technical tool (Anderson, 1996) but also by addressing the social aspects that require collaboration between organizations. In promoting organizational cooperation, emphasis should be placed on fostering innovation and the transfer of geographic data and technology through; 1. Partnerships and research networks among government agencies, research and training institutions, the private sector and the non government sector and 2. Advocating for international collaboration and cooperation between developed and developing countries

6.5 Setting aside yearly budgets for the defined activities

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

6.6 Adoption of the dynamic segmentation data model

There is no existing data model used for the GIS-T (GIS for Transportation) in Uganda. The traditional data storage within the GIS is basically tabulated data. However, the dynamic segmentation (DynSeg) data model is considered a superior data storage strategy within the GIS-T. DynSeg is the process of transforming linearly referenced data (also known as events) that have been stored in a table into features that can be displayed, queried and analyzed on the map (Mohammad *et al.*, 2009) through computations. It is widely used in GIS-T as an efficient measure to manage the heterogeneous attributes along the roads without any redundant data storage (Eddie, *et al.*, 2002). This in turn allows for less storage space, quicker data processing, and more information storage.

7.0 CONCLUSION

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

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