An Object Based Geographical Information Systems for Transportation (GIS-T) Data Model for Road Maintenance in Uganda

Mazzi Lydia Kayondo-Ndandiko[1], Gerhard Bax[2] and Sandy Stevens Tickodri Togboa[3]

[1] Lecturer College of Engineering, Design, Art & Technology, Makerere University, P. O. Box 7062, Kampala, Uganda.
Corresponding author e-mail: Lndandiko@gmail.com; mklydia@tech.mak.ac.ug; lmk@bth.se
[2] Professor, Blekinge Institute of Technology, P.O. Box 214, S-374 24, Karlshamn, Sweden
[3]Professor, College of Engineering, Design, Art & Technology, Makerere University, P. O. Box 7062, Kampala, Uganda.

ABSTRACT
This paper presents an object based Geographical Information Systems for Transportation (GIS-T) data model for road maintenance in Uganda. It is part of research aimed at accentuating the use of Geographical Information Technologies for road maintenance. Specifically, the study aimed at defining a GIS-T data model for road maintenance based on the data requirements in the sector as a process towards establishing standards for geographical datasets. This was accomplished through identification of road maintenance data requirements, review of organisational reports, workshop proceedings, organisational terms of reference for various projects, understanding and consideration of the Information Quality Levels (IQL) and a review of existing data models and standards in transportation. This resulted into a conceptual and logical data model for road maintenance based on concepts of dynamic segmentation and linear referencing. The study concludes that understanding of the transportation network of the country is essential to adoption of the proposed model. The choice of the GIS software for the physical model implementation with a full set of dynamic segmentation tools is fundamental.

Key words: GIS-T, Data model, Road maintenance, Uganda

1.0 INTRODUCTION

The maintenance of a country's transport network is pivotal to the overall infrastructural development of that nation. In Uganda however, there are several cases of poor transport services caused by the bad state of roads. Uganda, geographic coordinates of 1^{0} 00' N and 32^{0} 00' E is located in Eastern Africa, in the west of Kenya, south of Southern Sudan and in the east if the Democratic Republic of Congo. Road maintenance in that pearl of Arica has since proved ad hoc until recently when the need for preventive maintenance is being appreciated and plans of making it a priority are in place. As the road features are geographically located, the use of Geographical Information Technologies (GITs) in collecting, managing and analysing road condition is paramount. And yet, these technologies are underutilized in the road maintenance sector. GITs are specialised Information and Communications Technologies (ICT) that are useful in collecting, managing and analysing Geographical Information (GI) for decision-making purposes. Despite the tremendous advances in GITs, the country has not fully institutionalised these technologies. These technologies include but are not limited to Geographical Information Systems (GIS), Remote Sensing (RS) and Global Positioning Systems (GPS). GIS are powerful computer-based tools for integrating and analyzing spatial data from multiple sources. GPSs are accurate worldwide navigational and surveying facilities based on the reception of signals from approximately 24 orbiting satellites which were placed into the orbit by the U.S. Department of Defense in the 1970s (Mintsis and Basbas, et al 2004). RS is the acquisition of information about an object or phenomenon without making physical contact with it. 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 and Wymannvon et al 2007). There are various initiatives in which the above technologies have been used to collect and manage data for road maintenance decision support in Uganda. However, these initiatives have either ended prematurely or their expectations have not been realised. Examples of these projects include the Management Information System (MIS) that was intended to assist the District, Urban and

Community access road authorities in the management of the roads in their jurisdictions. Kampala City Council, now Kampala City Council Authority (KCCA), in 2003 housed a capacity building project where GIS was used to collect and manage relevant information on Kampala city roads. This project also ended prematurely. And yet there has not been research on ground that is investigating the challenges faced by the use of these technologies.

This paper is part of research aimed at accentuating the use of GITs for Road Infrastructure Maintenance (RIM) in Uganda. The study accessed the gaps and limitations to GIT initiatives for road maintenance and developed a methodological framework for enhancing the use of GITs in RIM. One of the limitations earmarked was the absence of standards for geographical datasets. Data standards are considered to come by easy from models of the entire structure of required data. The scope of this paper is presentation of a model for the structure of road maintenance data. This model was developed basing on the principles of dynamic segmentation and linear referencing.

2.0 METHODS

The following methods were adapted in the above study. Identification of the road maintenance data requirements was mainly through document and datasets review, observations and interviews. Interviews were also conducted to generate an in depth understanding of the processes of decision making for road maintenance. A broad picture of the data requirements involved was obtained. This was combined with reviews of organisational reports, workshop proceedings, organisational terms of reference for various projects, etc. An understanding and consideration of the Information Quality Levels (IQL) data categories was made. IQL correlate to the degree of sophistication required for decision-making and the methods for collecting and processing the data (Bennett and Chamorro et al 2007). This entailed generating knowledge of the various data views at the different levels of decision-making. Also, a review of existing data models and standards in transportation was made. Reference is made to Kayondo and Bax et al (2011). This was linked to an assessment of the existing data models within road maintenance organisations in the sector. The different data structures, attributes of the road as the transportation feature of interest, etc. were analysed. Field visits and observations were cyclically conducted. Lastly, in a workshop attended by personnel from the organisations in road maintenance, aspects of the proposed data model were presented and discussed. This harmonised position led to the conceptual and logical data models presented herein. In these developed models, the concepts of dynamic segmentation and location referencing are emphasized.

2.1 Dynamic Segmentation

Dynamic Segmentation is the process of computing the location of events along a linear feature, the road in this case. As documented by Kennedy and Shalaby 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. Butler and Dueker (1998) comment and advise accordingly "Individual agencies can use whatever methods they desire to segment and attribute highways and other transportation features. However, such customized approaches preclude easy data sharing with other potential users. The first step in facilitating data sharing is to adopt a uniform way of identifying maintenance required transport facilities. To do this, user needs of the participating organisations need to be translated into a data model as a first step to reach consensus on the database design and data sharing standards". Dynamic segmentation has been earmarked as effective in highlighting these consistent segments. It is a way of referencing linear attribute data on demand, based on a variable segmentation of a single network. The dynamic segmentation process imposes two requirements on the data; 1: Each event in an event table must include a unique identifier and position along a linear feature and 2: Each linear feature must have a unique identifier and measurement system.

2.2 Location Referencing

The road condition data necessary for road maintenance decision-making should refer to specific points or sections of the road. Reference to these points and sections is a prerequisite for planning strategies to undertake maintenance. Since roads and geographically placed, geographical reference to these locations is paramount. Equally important and fundamental is the geographical location of the entire road in consideration within the jurisdiction context. Bennett and Solminihac, 2006 maintain that location referencing is the singularly most important consideration in conducting a survey. They argue that unless the data are properly referenced, they will be of limited use in making management decisions. This makes location referencing 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, 2002). There are majorly two ways of locating location of features on the road network; linear and spatial location referencing.

2.2.1 Linear Referencing

The linear referencing system of a road is the foundation to the location and analysis of events on the road network. 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. It 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 and Harkey et al 2001). Various linear referencing methods exist, for example, location can be given in terms of kilometre point method (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 stations) and the link node method. The link node method is a special implementation of the generic referencing system. The nodes refer to specific logical locations on the roads and the links are logical 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.

2.2.2 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 networks objects. Dynamically linking 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 that can be spatially referenced, the basic rule for GPS referencing is that only those data that are most suited to spatial referencing should be spatially referenced (HTC, 2002). In principle, spatial referencing should not take over linear referencing! The two-dimension coordinates are hard to obtain and hard to match the maps (Zhu and Jiang, 2009), and since the transportation network is linear, attribute information is stored on some road sections and points, so one-dimension linear reference system is suffice to be adopted as the method of reference to this attribute information. Spatial referencing is generally required for: reference stations and other key referencing features, the road centreline, off road objects, such as signs, which cannot be referenced using displacements and offsets (HTC, 2002) and 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. These however also need linear locational reference as a complement.

3.0 RESULTS

3.1 CONCEPTUAL DATA MODEL

The success of GIS is highly dependent on information structure analysis and conceptual data modelling (Demirel, 2002). In reality, there are numerous views that result into conceptual models. Figure 1 shows the levels of data modelling, and points to the several views from which a conceptual data model can be taken. The choice of which presentation to use at this stage depends on what data is being modelled, the modeller and in other circumstances, the audience.

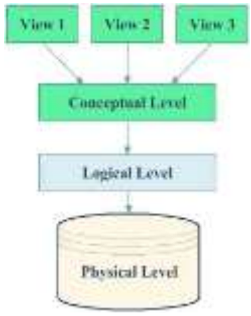

Figure 1: Levels of Data Modelling
Source: Elmasri and Navathe (2007

The view taken in this research is presented using an Entity Relationship Diagram (ERD). Figure 2 shows the proposed conceptual data model for road maintenance in Uganda. Basically, three groups of entities are modelled. The road's network, the point and line events that exist on it. Clearly from the figure these three entities are distinguished.

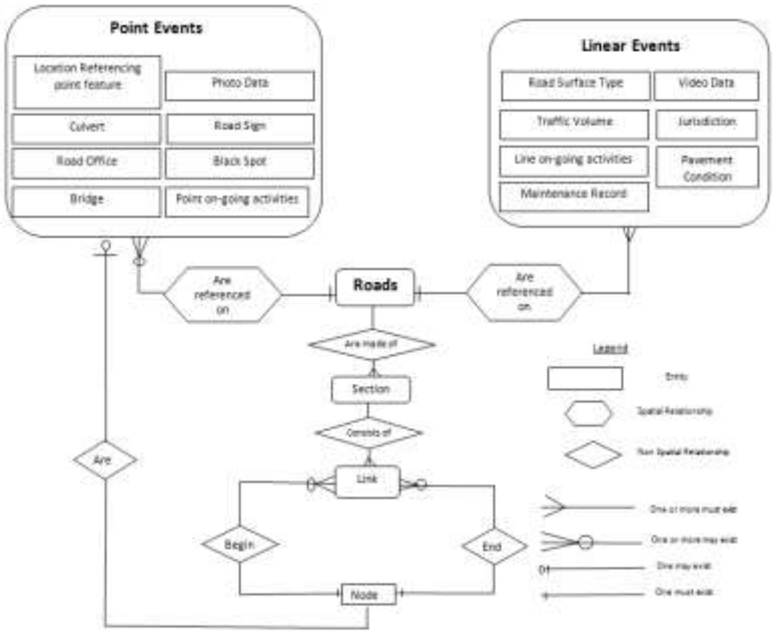

Figure 1: Conceptual Data Model - Entity Relationship Diagram
Source: adapted from Niaraki et al., (2009)

3.2 LOGICAL DATA MODEL

The object relational data model was selected for the logical data model. This was intended to balance between the combined advantages of the concepts of objects and methods from the object oriented model and those from relations of the entity relationship models. The relational data model has superiority in effecting standard queries using the standard query language (SQL). Additionally, it accommodates database versioning, is 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 is quite large compared with others systems. This is envisaged to make the system performance low. The design of a combined object relational data model to benefit from the relational database technology that is available across a variety of platforms was fundamental. Furthermore, 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. Since majority of the existing databases in the study area were relational, and yet object oriented data modelling possess superior advantages of providing solutions to identified problem areas, a hybrid object relational data model was considered for the sector. It has enhanced spatial query opportunities that can be easily performed since the complex objects are stored in tables each with their object identifiers.

ESRI provides data model templates for use, extension and adoption to various systems. Its 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. Besides logically documenting the various classes from the conceptual data model, the ESRI provided template for logical data modelling was used. Figure 3 shows the proposed logical data model for the sector[1].

The model was based on 5 business rules guided by the mandate and objectives of the organisations involved in road maintenance. These rules include;

1. Emphasis of the model is on the events that occur on the transportation system. The geographic datum, links and nodes that form the base network are only inferred.
2. The point and linear events on the road as the transportation feature are located using a linear location referencing system based on a cumulative distance offset, referred to as chainage, from the beginning point of the road section.
3. Only one linear referencing system is used to relate point and linear events to the road.
4. All events must be related to the road; i.e., exist on, at, or adjacent to the road.
5. Because of the complexity in implementing Many to many (*...*) relationships, they have been avoided in the model

The multiplicity in the model is explained in table 1.

Table 1: Multiplicity Explained

Indicator	Meaning
0..1	Zero or one
1	One only
0..*	Zero or more
1..*	One or more

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

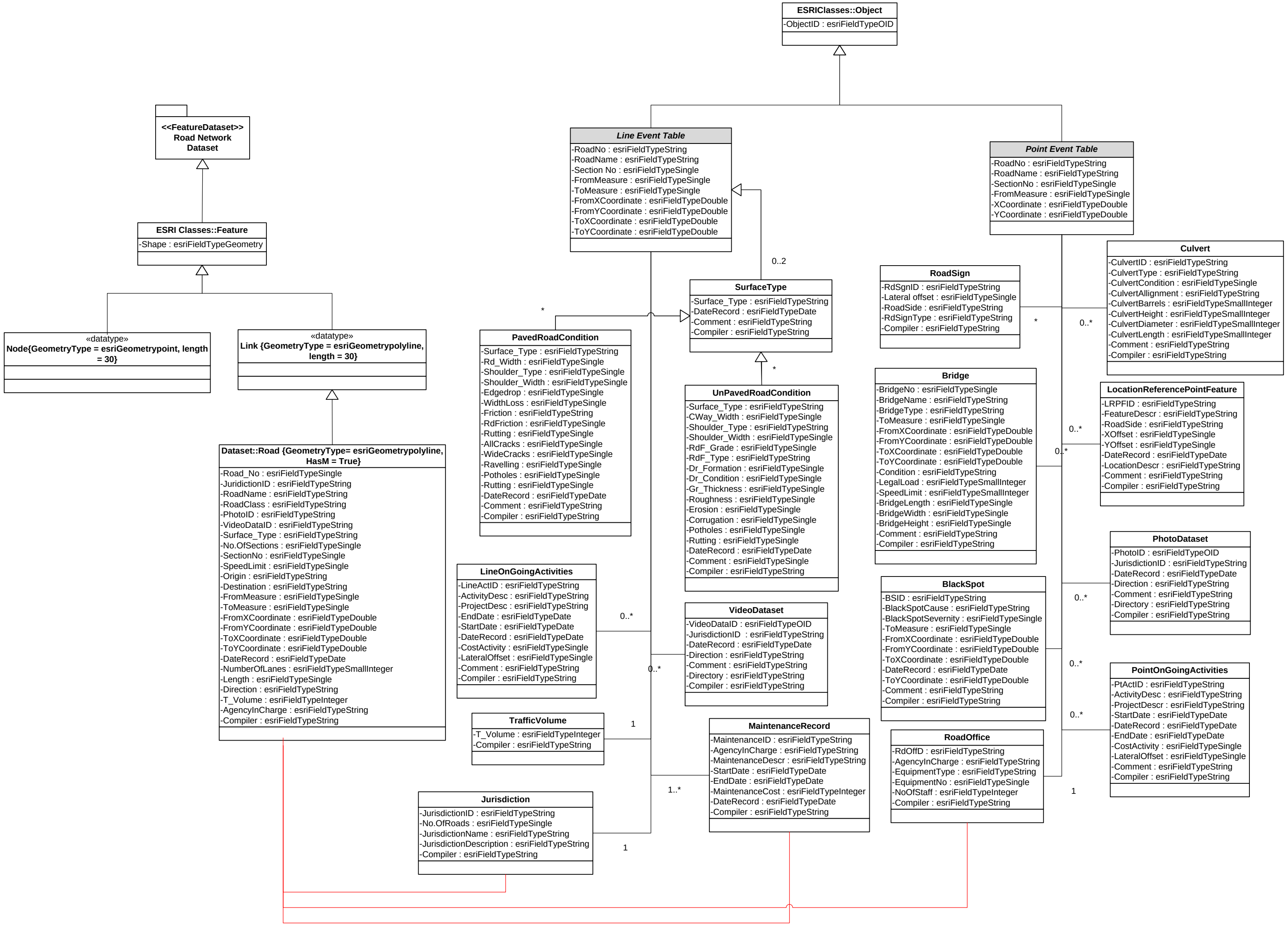

Figure 3: The Proposed Logical Data Model

From the logical model, we identify with a total of 17 classes namely; Road, Jurisdiction, MaintenanceRecord, Line On Going Activities, Unpaved Road Condition, Paved Road condition, Traffic Volume, Bridge, Culvert, Photo dataset, Video dataset, Road Surface Type, Road Sign, Black Spot, Road Office, point On Going Activities and location Reference Point Feature. The road is the route class of the model on which the linear and point event objects are located. The MaintenanceRecord, Road office and Jurisdiction are referenced directly to the road. The Unpaved and Paved road condition classes are subclasses of the Road Surface Type. Each of the classes has a couple of named attributes with assigned data types.

4.0 IMPLEMENTATION OF THE PHYSICAL DATA MODEL

A common understanding of the transportation system in Uganda is the backbone to using this proposed model. An explicit definition and documentation of the anchor points and sections that define the road network of the country is fundamental. These should be inclusive in the location referencing points feature dataset. This requires uniform and agreed mechanisms of defining road sections. Dueker and Butler (1999) propose the use of either pavement type, functional type, jurisdiction, and intersections to define logical sections so as to create discrete transportation features according to some business interest. Specific locations for the beginning and ending point measures for linear objects should be assigned and documented accordingly.

The ability to access and use tools that can manage and query linearly referenced data in GIS is quite critical especially now, as the use of GIS in transportation (GIS-T) agencies is being advocated for. A GIS platform that supports dynamic segmentation will be ideal. Not all GIS have the capability to perform analyses based on dynamic segmentation. The choice of the GIS platform should take this into consideration. Most users with ArcView, Geomedia and other desktop GIS software do not have access to the full set of dynamic segmentation tools (Sutton and Wyman, 2000). However, ESRI’s ArcGIS and Intergraph have dynamic segmentation data models in their software.

5.0 CONCLUSIONS

The purpose of the developed model is to aid spatial analysis for decision making in road maintenance operations. It is the linear referencing system that allows dynamic segmentation capabilities to be implemented on the road network. Linear referencing and dynamic segmentation together provide the user with the ability to perform spatial analysis. The existence of a GIS-T data model is a drive to enhancing the use of GITs in road maintenance. It is a step towards standardising datasets for the sector. However, before assuming the proposed model, an in depth assessment of the software to adopt is a requirement.

6.0 ACKNOWLEDGEMENTS

The authors would like to acknowledge the organisations under which the research was accomplished. The study was sponsored by Sida, Sweden for whom we are indebted. The administration, staff and colleagues from the academic institutions of Blekinge Institute of Technology, BTH, Karlsahmn Campus, Sweden, and Makerere University, Uganda are similarly acknowledged for the good administration, guidance and comradeship during the research undertaking.

References

Bennett, C. R., Chamorro, A., Chen, C., Solminihac, H. D. and Flintsch, G. W. (2007).“Data Collection Technologies for Road Management.”World Bank, East Asia Pacific Transport Unit.

Bennett, C. R., Solminihac, H. D. and Chamorro, A. (2006).“Data Collection Technologies for Road Management”Transport Notes, Roads and Rural Transport Thematic Group. The World Bank

Bishop, I. D., Barry, M., Mcpherson, E., Nascarella, J., Urquhart, K. and Escobar, F., (2002).“Meeting the Need for GIS Skills in Developing Countries: The Case of Informal Settlements.”*Transactions in GIS,* 6 (3)**,** 311-326

Demirel, H. (2002). “An Integrated Approach to the Conceptual Data Modelling of an Entire Highway Agency Geographic Information System”.*Institute of Geodesy and Geo information Technology* Berlin Technical University. PhD. 131 p

Dueker, K. J. and Butler, J. A., (1998).“GIS-T Enterprise Data Model with Suggested Implementation Choices.”*The Urban and Regional Information Systems Association (URISA),* 10 (1)**,** 12-36

Dueker, K. J. and Butler, J. A. (1999).*GIS-T Data Sharing Issues.* Discussion Paper 99-02, Centre for Urban Studies, Portland State University

Ehrensperger, A., Wymannvon , S. D. and Kakridi, F. E., (2007). Geographic Information Technologies for Natural Resource Management.*InfoResources Focus,* No 3/07

Elmasri, R. and Navathe, S. B., (2007).“Fundamental of Database Systems”5th Edition. USA, Addison Wisely

HTC (2002).“Road Information Management Systems: Location Referencing System Guide for Road Controlling Authorities.”HTC Infrastructure Management Ltd. http://www.lpcb.org/lpcb-downloads/data_collection/2002_rims_location_referencing_guide.pdf. 19-04-2012

Kayondo, L. M., Bax, G. and Tickodri-Togboa, S. S. (2011). “Geographic Information Systems for Transportation - Data Model for Road Infrastructure Maintenance in Uganda.”*The first Conference on Advances in Geomatics Research* Makerere University, Kampala - Uganda.

Kennedy, J., Shalaby, A. and Cauwenberghe, R. V. (2000).“Dynamic Segmentation of Pavement Surface Condition Data.”*3rd Transportation Speciality Conference of the Canadian Society for Civil Engineering.*London, Ontario.

Mintsis, G., Basbas, S., Papaioannou, P., Taxiltaris, C. and Tziavos, I. N., (2004). “Applications of GPS Technology in the Land Transportation System.”*European Journal of Operational Research,* 152 (2)**,** 399-409

Niaraki, R. M. J.-., Ali AsgharAlesheikh, Abbas Alimohammadi and Sadeghi-Niaraki, A., (2009). “Designing Road Maintenance Data Model Using Dynamic Segmentation Technique.”*Journal of the International Conference on Computational Science and its Applications (ICCSA),* 5592 (Part I)**,** 442 - 452

Smith, R. C., Harkey, D. L. and Harris, B. (2001).“Implementation of GIS-Based Highway Safety Analyses: Bridging the Gap.”Federal Highway Administration.http://www.fhwa.dot.gov/publications/research/safety/1039.pdf.

Sutton, J. C. and Wyman, M. M., (2000).“Dynamic Location: An Iconic Model to Synchronize Temporal and Spatial Transportation Data.”*Transportation Research Part C: Emerging Technologies,* 8 (1-6)**,** 37-52

Zhu, W. and Jiang, G. (2009).“A New Extended Arc-Node Data Model of Dynamic Segmentation Technology in Urban GIS-T.”*World Congress on Software Engineering, 2009 (WCSE '09.).*Xianglu Grand Hotel, Xiamen, China.