DEVELOPMENT OF AN URBAN ROAD MAINTENANCE MANAGEMENT SYSTEM FOR TAMALE

by

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A Thesis submitted to the department of Civil Engineering,

Kwame Nkrumah University of Science and Technology

In partial fulfillment of the requirements for the degree of

MASTER OF PHILOSOPHY

Faculty of Civil and Geomatic Engineering

College of Engineering

May 2007

DECLARATION

I, Adi, Solomon Buenor , hereby declare that this submission is my own work towards the M.Phil, and that to the best of my knowledge, it contains no material previously published by another nor material which has been accepted for the award of any other degree of the University, except where due acknowledgement has been made in the text.

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DEDICATION

This work is dedicated to all whose aspiration in life is to leave behind footsteps in the sand of time.

ACKNOWLEGEMENTS

To God be the Glory for this successful step up the academic ladder which has also been with the instrumentation of many far and near. My candid appreciation goes to my Supervisors Mr. Charles A. Adams, Dr. M. S. Salifu and Dr. Eric K. Forkuo for the support and guidance during this course. May God richly replenish all lost virtue. My sincere gratitude to other lecturers at the Faculty of Civil and Geomatic Engineering especially, Prof Esi Awuah and Dr. C. S. K. Kpordze as well as the Maintenance Unit of the Department Urban Roads, Tamale, Kumasi, Cape Coast .

To my Parents and dear sister, Diana I am eternally grateful for your love, prayers and warmth. And to my dear Miss Doreen Dedo Opata, God bless you and grant you your heart desires for the priceless roles you played to make this dream a reality.

And to Mr. Kwaku Agyei, Mr. Mark Amo-Boateng and APC, I will always treasure the memory of your priceless input into this system development. Then to all those who have contributed in one way or the other, directly and indirectly especially the Leadership and Members of the Presby Church of Ghana, Ayeduase for your prayers and offering me the opportunity to make my stay a training and refining one for the Masters use. May the Lord continue to uphold you all with His victorious right hand in all your endeavours.

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LIST OF ABBREVIATIONS

- AASHO: American Association of State Highway Officials
- AASHTO: American Association of State Highway and Transportation Officials
- CPMS: Chinese Pavement Management System
- DSS: Decision-Support Systems
- FHWA: Federal Highway Administration
- HDM: Highway Development and Management Standards Model
- HMS: Highway Maintenance Management System
- GIS: Geographic Information System
- ICT: Information and Communication Technologies
- IQL: Information Quality Levels
- IS: Information System
- IRI: International Roughness Index
- IT: Information technology
- LCPC: Laboratoire Central des Ponts et Chaussees
- LRS: Linear Reference System
- MIT: Massachusetts Institute of Technology
- NEEDAS: GIS-enabled multi-year pavement needs analysis system for
- NLS: Network Management System
- NRSC: National Road Safety Commission
- ORN: Overseas Road Note
- PCR: Pavement Condition Rating
- PCI: Pavement Condition Index

- PMS: Pavement management system
- PQI: Pavement Quality Index
- PSI: Pavement Serviceability Index
- SDSS: Spatial Decision Support System
- TRRL: Transport and Road Research Laboratory
- VOC: Vehicle operation cost

ABSTRACT

An urban road maintenance management system has been developed in this study. The seeks, among others, to address the non motorized transport peculiar need of the road network in Tamale.

A road condition survey was undertaken in 2004/2005 on the Tamale road network to collect primary data for the development of the system. Road definition, inventory, defect and NMT lane data were collected. The data was used to develop an MS Access 2003 desktop database and also update a digitized Tamale road network map in GIS environment. Visual basic.net programming language was used for the decision support tool development.

Cost of treatment of different road defects were studied from the maintenance unit of the Department of Urban Roads and the Department of Feeder Roads and questionnaires on agency and road user perception of the destructive nature, cost of repair and effect on riding comfort of various defects were also administered to engineers in these agencies and road users. Coupled with work from literature, a customized pavement rating form was developed to calculate the pavement condition index (PCI) of road links.

The system recommends appropriate treatments in relation to the PCI of every link and ascertains its condition assessment. Based on the PCI category, the functional classification, economic factor and the traffic level of the road, the urgency of the treatment of one link over another was generated. Customized thematic ArcGIS maps were developed capable of displaying the different road classes, pavement types and the number of the different functional classes of roads within the Tamale network was established as 64, 149, 430 and 495 respectively for A, B, C and D roads. Maps on location of drains, culverts, traffic lights and other road inventories

could be shown. Reports could also be saved, e-mailed and exported MS Excel, PDF, CSV document, text document, graphic document, etc. for further analysis.

Chapter I

INTRODUCTION

1.1 Background Information

Good roads generally improve the economic and social welfare of people by lowering the cost of vehicle use, increasing access to markets, jobs, education, tourist sites and health services, security services, and reducing travel times, transport costs for passengers and freight (GHA-HNMP, 2000).

Road transport is an essential factor in the economic growth of developing countries. It provides for 85 % or more of total inland and/or border crossing traffic. Cost-effective road infrastructures and their systematic maintenance are therefore vital (OECD, 1995).

In Latin America and the Caribbean, road transport has been the backbone of passenger and freight transport for the last 50 years and these extensive road networks, valued over 350 billion US dollars, continues to show alarming signs of neglect and decay. More than 16 billion US dollars are wasted annually due to the absence of adequate road maintenance in Latin America. Individual countries are losing between 1% and 3% of their annual GNP due to an unnecessary increase in vehicle operating cost and loss of road asset value alone. The devastating situation is not only true for Latin American countries, but can be found in other developing countries and some developed countries as well (Zietlow, 2000). The road is the principal transport facility in Ghana responsible for 97% and 94% of all national passenger and freight traffic respectively. Thus it will continuously play a primary role in the socio-economic growth in the medium and long term (GHA-HNMP, 2000).

1.2 Problem Statement and Justification of Research

For any road manager, information on the inventory, condition maintenance history, types of facilities provided, cost of maintenance and traffic is very essential for proper and objective management. In Ghana, the Ghana Highway Authority system Pavement Maintenance Management Programme (PMMP) was introduced in 1995 and is still running but lacks some of these features. For urban road network management, a current system is under development in the Department of Urban Roads. When completed, this is expected to improve upon the PMMP in features and make it easy to manipulate and manage urban roads in metropolitan and municipal areas.

Tamale however, stands out as the only metropolis where screenline count on any road will indicate that over 50% of the transport is by Non-Motorised Transport especially cyclists. In recent years, some investments have been made to develop cycle lanes in Tamale. One system for all metropolitan and municipal areas means the likelihood that Tamale's peculiar network characteristics and needs may not probably be well addressed. Most road management systems worldwide give much attention to motorized road networks. Since NMT's dominate within the Tamale network, this project seek to develop a system that would have features of an information system with a module on NMT facilities which will allow for the planning of NMT facilities along with all other road assets.

1.3 Objectives

The objective of the study was to use the Tamale road network to develop a decision support tool for urban road maintenance management with the following capabilities:

- a network information module for assembling, storing and retrieving of all relevant inventories, conditions and NMT lanes of the Tamale road network.
- a decision support module to process network data and select treatment alternatives
- prioritize roads in order of importance for treatment due to budget constraints.

Chapter II

LITERATURE REVIEW

2.1. Introduction

Municipal infrastructure cannot be completely protected from deterioration due to usage, climatic effects or geological conditions. Furthermore, because of inadequate funding or inappropriate support technologies, certain components of this infrastructure have been neglected and received only remedial treatments. Preventive maintenance programs are being developed and implemented as cost-effective strategies for accomplishing an agency's preservation goals (Zimmerman and Peshkin, 2003). The effect of lack of maintenance on road users is also significant, with vehicle operating costs increasing by similar or greater amounts (Parkman *et al*, 2002).

Road maintenance as defined in the UN Road Maintenance Handbook consists of routine and periodic activities to pavements, shoulders, slope drainage and all other structures and property within the right of way to keep them as nearly as possible in their as-constructed or renewed condition (OECD, 1990).

Also according to OECD (1995), the major objectives of road maintenance management are to provide economic and managerial framework for deciding the optimal level of maintenance funding and the optimum level of pavement condition both long-term and short-term perspectives, provide sound methods for developing annual works programmes and determine resource requirements and budgets, allocate funds in a national and optimized manner to the various maintenance tasks and administrations, particularly under budgetary constraints and the future deterioration of pavement condition. This is implemented through a road management process which according to

Tillotson *et. al.*, (1998) its main aim is to make the best possible use of resources available and maximize benefits to society. It comprised factors such as; inventory, condition, traffic, deterioration, costs and benefits, resources, budget, standards and policies, management information etc.

2.2. Road Maintenance Management Systems

Effective road management requires continuous access to information about every aspect of the road network and the activities undertaken to keep it in good condition. With their power and relatively low cost, modern computer systems are ideally suited to assist in this task, particularly where large amounts of data have to be managed.

All notwithstanding, the sole purpose of computer-based systems is to support the human resources engaged in the management process and so much can be achieved in road management through the use of manual techniques; operating check-lists, equipment use and maintenance cards, diagrams and wall charts (ORN 15, 1998)

Table 2.1 (Robinson *et al.,* 1998) presents examples of the way systems offered in support of road management functions are commonly described and some pavement management systems (PMS) developed over the years and comments on what triggered their development are listed in table 2.2 . A typical schematic diagram of a maintenance system as outlined in table 2.1 is presented in Figure 2.1.

Table 2.1: Functions of Pavement Management Systems

MANAGEMENT FUNCTION	SYSTEM DESCRIPTION
Planning	Strategic analysis system Network planning system Pavement management system
Programming	Programme analysis system Network planning system Budgeting system
Preparations	Project analysis system Pavement management system Pavement/overlay design system Contract procurement system
Operations	Project management system Maintenance management system Equipment management system Financial management /accounting system

Source: Robinson *et. al.* (1998)

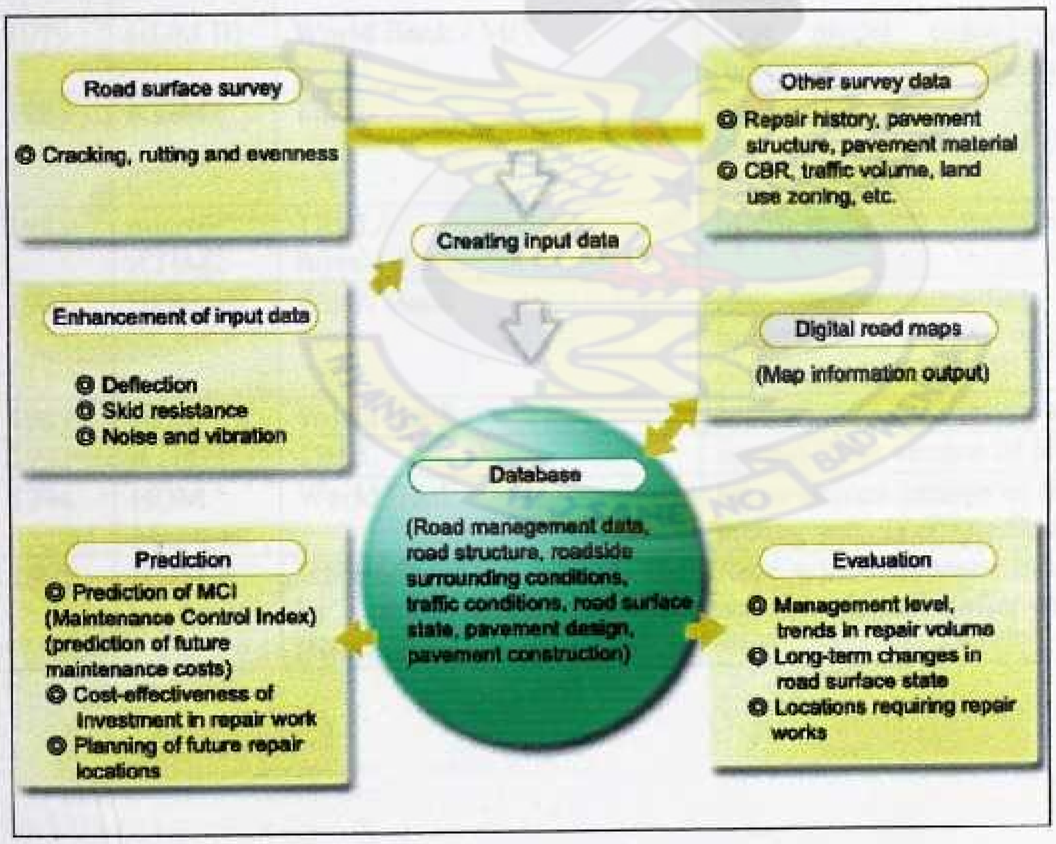

Figure 2.1 Schematic Diagram of a Maintenance Management System
Source: (www.dot.state.az.us/TPD/ATRC/publications).

2.2.1 Levels of a Road Management System

A Road Management System (RMS) operates primarily at two different levels, network level, and project level. The project level deals with the details of work coming "on stream". Very detailed information on the asset condition and performance is obtained. A network level decision may involve the preparation of a rehabilitation and maintenance schedule and the ranking of the priorities within a pavement network.

Table 2.2 Some Pavement Management Systems

DATE	NAME	DEVELOPER	COMMENTS
1968	HCM	MIT/World Bank	Based on literature of relevant work
1975	RTIM	TRRL/World Bank	New model extending HCM to incorporate results of field work in Kenya
1979	HDM III	World Bank / MIT	New model extending RTIM to increase analytical capacity
1982	RTIM2	TRRL	Simplified version of RTIM also incorporating results of the field work in the Caribbean
1985	micro-RTIM2	TRRL/ university of Birmingham	Micro-computer version of HDM-III
1987	HDM-III	World Bank	New model extending HDM-II and incorporating results of field work in Brazil and India.
1989	HDM-PC	World Bank	Micro-computer version of HDM-III
1993	RTIM3	TRRL	Spread sheet version of RTIM2
1994	HDM Manager	World Bank	Menu-driven version of HDM-PC, later adding vehicle congestion relationships
1998	HDM-4	International consortium led by the University of Birmingham	New windows-based model extending and updating all earlier versions

2.3 Components of a Road Maintenance Management System

2.3.1 System Requirements and Specifications

A PMS developed for a western country may be inadequate for a country with very different traffic characteristics and administrative structure (Tillotson, *et al*, 1998). The framework however could be comparable. Figure 2.1 shows a simplified framework for a maintenance management system comparable to Bernhardt et al. (2003) asset management system components whose was derived from the generic framework for asset management proposed by the FHWA's Office of Asset Management (FHWA, 1999). In it, the basic components of an asset management system are subdivided into particular activities or types of data.

2.3.2 System Platform

The system platforms reviewed for the system spatial database component were Arcview 3.2, ArcGIS 9.0 and ArcGIS 9.2. Arcview 3.2 was more rigid in use and the ArcGIS 9.0 and 9.2 have advanced features and worldwide use currently. The ArcGIS 9.2 has the ability to access data directly from Microsoft excel. The database platform considered for the non-spatial data were Microsoft Access 2003, Microsoft Sequel Server 2000 and Microsoft Sequel Server 2005. Factors used to evaluate these were easy accessibility, widespread use, training of local personnel to use it, the ease of use and the size of data the platform could handle.

2.3.3 Programming Language

The programming languages reviewed were Visual Basic 6.0, Visual Basic.Net, Borland Delphi (Wilkepedia.com) and Visual Basic Applications (VBA) in ArcGIS. Visual Basic Applications in ArcGIS has already been built into the ArcGIS software which solves all linkage problems which normally arise due to incompatibility of languages but has much rigidity in terms of use and poor Graphical User Interface (GUI) design features compared to visual basic.Net, Borland Delphi, C++. These latter ones are always seeing upgrades which offer a better up-to-date design than the visual basic application. Factors used for the selection of the system platform were used for the language selection as well.

2.3.4 Selection of Hardware and Operating Systems

The last decision that should be made when planning the implementation of a highway management system is the choice of hardware on which the system will run: this is contrary to the approach taken by almost all projects to develop and implement systems in the past (Robinson, 1995). In most cases, once the requirements of the management system software have been defined, and the choice of operating system has been made, the choice of hardware will be self evident. A system based on microcomputers should be considered as a starting point in many cases because of the availability of hardware maintenance. But the use of work-stations should not be overlooked, particularly where large data volumes are anticipated. At a cost of little more than a micro, large gains in efficiency of data storage and operation can be obtained (Robinson, 1995).

2.4. Institutional Framework

Road management is influenced by the state of a country and its government policies on investment. The institutional factors in context include organizations and managerial arrangements, finance and human resources (Robinson *et al.*, 1998). Table 2.2 outlines the organizations and institutions ensuring consistent improvement of earlier developed systems in the world. These institutions fund, monitor and implement as well as evaluate developed systems. The systems must be structured to support the primary management functions of: planning, organizing, directing, and controlling. Unfortunately, experience according to World Bank DOC1101 Issue 1, (1997) citing Robinson (1995), the implementation of systems in many countries has been disappointing due to:

(i) user attitudes; which involves lack of genuine commitment to the implementation, expectation of high-tech solutions when, in fact, simple common sense solutions are appropriate and resistance to change.

(ii) cultural issues; problems of introducing modern management practices, including incentives and into cultures with no management tradition,

(iii) economic and financial problems; weak local economies and foreign exchange shortages preventing the purchase of even basic commodities needed to support the system and local budgets dominated by the payment of staff salaries, with residual funds being insufficient to pay for maintenance works to be carried out;

(iv) key staff positions not filled, or filled with staff of insufficient experience;

(v) training; operational requirements preventing local staff being released for training, over-ambitious training programmes with instructors being inadequately prepared and insufficient follow-up training and revision;

(vi) deficient computer facilities and inadequate availability of hardware;

(vii) poor availability of existing data; and

(viii) systems being too complicated and demanding to be sustained with local resources.

Based on this past experience, steps were recommended to specifying and selecting systems in order to avoid these pit-falls. These steps could hardly be met and therefore academia still goes on with research and shelves these till need be of by governments and organizations. But these often fall short of the full requirement of these institutions in terms of the scope and depth of the output of the research often due to low funding, lack of needed data and tools.

2.5. Assessment of Some Maintenance Management Systems

2.5.1. Chinese Pavement Management System (CPMS)

This was an adaptation of Finnish Model RMMS customized for the Jiang Su Province road network in China (OECD, 1995), composed of three parts: the pavement database, network level management system, and the project level management system.

The Pavement Data System (PDS) constituted the information centre of the CPMS and performed such functions as: data edit, retrieval, calculation, tabulation, statistics, drawing and creation of other data files as required. The Network Management System (NLS) was a macro decision-making system based on investment analysis, maintenance demand analysis and pavement condition analysis at network level.

The Project Management System (PLS) was the decision-making system for maintenance of one or several road sections. It was composed of the five modules. The two systems were run one after the other. Project level decisions are made based on NLS analysis.

Some additional data required for PLS data preparation comprise; pavement deflection, roughness, distress, friction coefficient etc. A decision tree method was used on both technical and economic factors. The PDS was made up of a code sub-system and a basic data sub-system. The code sub-system included eight-files: the road code, the administration region code, section code, sub-section code, surface type code, base type code, sub-base type code, treatment code. The basic data sub-system included six files: traffic volume data, road distress data, pavement deflection data, comprehensive index data, pavement treatment historical data, and macro-economic data. The NLS comprises of five parts: data preparation, model parameter modification, optimization, demand analysis and results output.

2.5.2. Computerized Maintenance Management System (CMMS)

Another existing tool that can be used to record what assets are owned is the computerized maintenance management system (CMMS). There now exists a large selection of "fully commercialized" CMMSs. Many of these are relational database applications that have been developed to meet the data handling needs of road managers. The CMMS domain, at this time, is quite mature, and many stable, comprehensive, useful tools exist (www.altivista.dignital.com). For example, any number of database applications can manage work orders, trouble calls, equipment cribs, stores inventory and preventive maintenance schedules, and many programs include features such as time recording, inventory control and invoicing. The CMMS's capability to store inventory data is formidable; however, their capacity with respect to life cycle economics, service life prediction and risk analysis is considerably less sophisticated. The CMMS is becoming an essential tool for the asset manager of the 1990's (www.excite.com). Quite a number of cites give credence to extensive use of CMMS on the internet but in the author's view the age of extensive use of CMMS is yet to become a reality in Ghana.

2.5.3 Highway Maintenance Management System (HMS-2)

HMS-2 (Figure 2.3) is an integrated highway maintenance management system. It is a new concept in maintenance management systems being designed to be open to the road agency to enable tuning of the activities of the system to local conditions following an initial consultation period without the necessity to rely on external consultants. HMS-2 comes as a simple to mount software package for use on any IBM compatible high specification PC. It was designed to be compatible with the latest economic models such as HDM-4 and indeed had been developed in and by the Highways Group of the University of Birmingham, who were responsible for the Technical Secretariat of HDM-4 working for the World Road Association. HMS-2 was written in Visual Basic with a choice of either an SQL Server or Microsoft ACCESS 97 as the database and is placed in a WINDOWS© environment for ease of use by different categories of users. In its design, it's customized to satisfy organizational goals. In Cyprus, new functions have been added which enable network referencing information and road condition data to be imported to HMS-2 as well as export routines which enable the highway data to be exported to a GIS system have been incorporated. Other countries which have HMS-2 tailored to their specific needs and requirements are Malaysia, Scotland and England. (HMS, 2005)

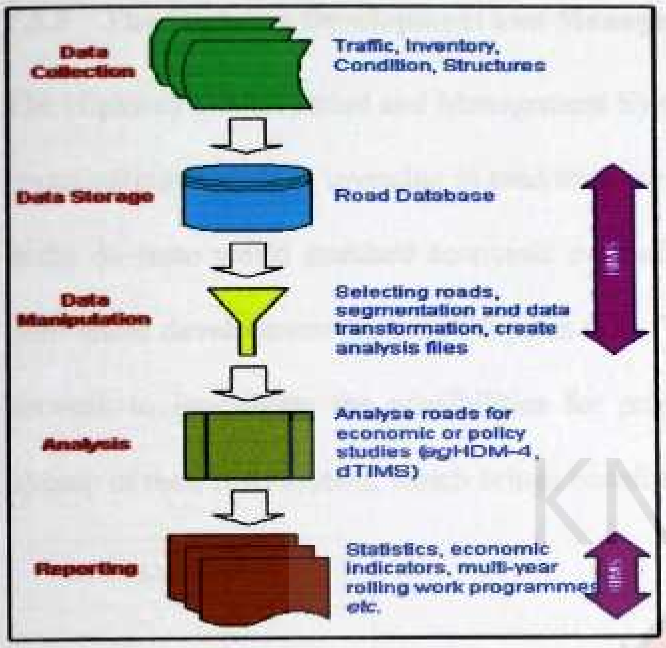

Figure 2.2: HMS-2 Flowchart.

Source: www.civ-hrg.bham.ac.uk/hms2/services.htm

2.5.4 Condition Assessment Survey (CAS)

This is another decision-support tool to establish the existing condition of the asset. A CAS produces a benchmark for comparison; not only between different assets, but also for the same asset at different times (NRC,1994). "Using CAS, a maintenance manager can formalize the assembly of basic planning elements such as deficiency-based repair, replacement costs, projected remaining life and planned future use" (Coullahan *et al.*, 1994). CAS records the deficiencies in a system or component, the extent of the defect, as well as the urgency of the repair work. The US Department of Energy has a significant programs (Earl, 1997) dealing with Life Cycle Asset Management/Condition Assessment Surveys

2.5.5 The Highway Development and Management Tool (HDM)

The Highway Development and Management System - HDM-4 - is a software system for investigating choices in investing in road transport infrastructure (Figure 2.4). This model is the de facto world standard economic evaluation tool for highways. The HDM had been under development for over 30 years now (Table 2.2). It enabled managers of road network to investigate the possibilities for providing cost-effective development and upkeep of their road system, which brings benefits to the communities that they serve.

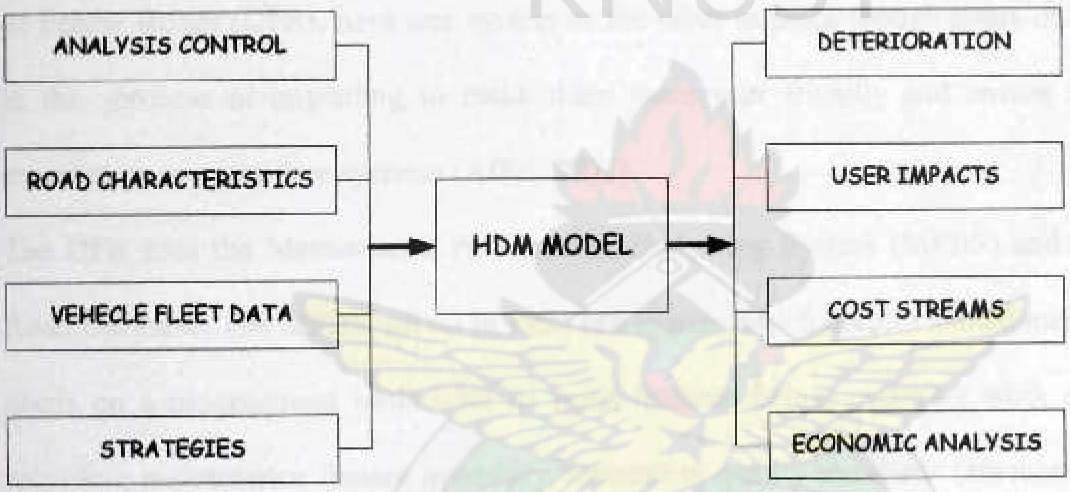

Figure 2.3 The HDM III model

Many of the early road deterioration models have therefore been upgraded. These upgrades have basically been to the technical relationships and the inclusion of additional capabilities such as traffic congestion effects, cold climate effects, a wider range of pavement types and structures, and environmental effects to the systems. It was for instance against this background that the development of HDM-4 was undertaken.

2.5.6 Road Maintenance Management Systems in Ghana

A number of researches had been carried out in this field in Ghana by the Faculty of Civil and Geomatic Engineering. Paramount amongst them was the review of the Pavement Maintenance and Management Programme (PMMP) used by the Ghana Highway Authority from a DOS based interface to a windows based interface and also to be able to store data on floppy disks. The road implementing agencies in Ghana; the Ghana Highway Authority (GHA), the Department of Urban Roads (DUR) and the Department of Feeder Roads (DFR), have one system or the other in place though many of them are in the process of upgrading to make them more user friendly and ensure that they measure up to up-to-date systems (Afful, 2007).

The DFR uses the Maintenance Performance Budgeting System (MPBS) and the DFR Road Database. The MPBS, set up in 1994 is a system which defines annual maintenance needs on a programmed basis with its main features being; outlining work activities, recording maintenance feature inventory, estimating quality standards (amounts of work planned per year), works programme establishing quantity of works and expressing the works programme in financial terms in the form of a performance budget.

The DFR Road Database is also a Microsoft Access road database system developed based on an inventory, spatial coordinates along the alignments and condition survey on roads within the jurisdiction of the department in Ghana.

The DUR Road Asset Monitor which metamorphosed from the PMMP is an Asset management system packaged to store road data, use defect based approach in condition evaluation and treatment selection, interface with ArcGIS for thematic map preparation and link up with HDM-4 for economic analysis.

The Pavement Maintenance and Management Programme used by the GHA is an information system, a decision support system, a planning and budgeting tool for road maintenance, development and efficient allocation of funds for optimal use.

The flowchart illustrating PMMP computerization process (Figure 2.5) outlines the inputs and outputs of the system. The original PMMP version has been upgraded but nevertheless still has limitations of inability to merge data files from different regions, which means that data input must be centralized, overdependence on roughness measurements for the evaluation of the road condition score and interface with GIS still not operational.

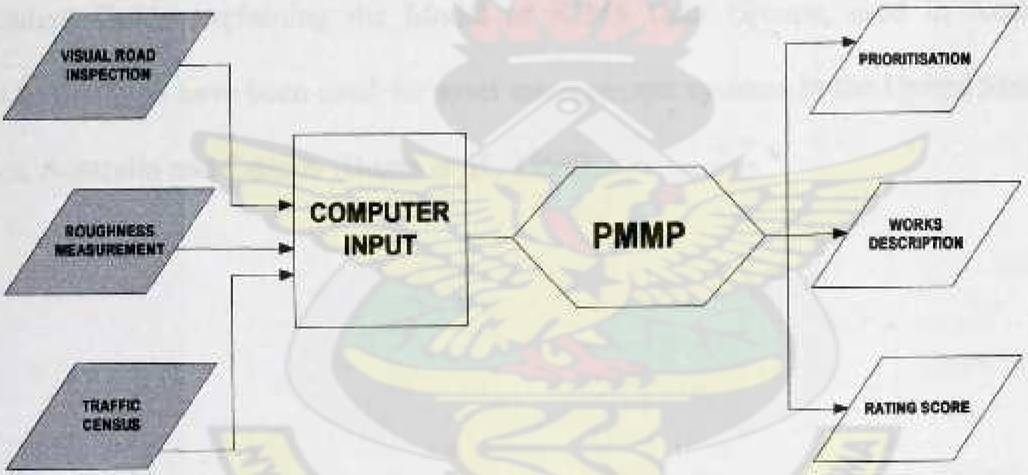

Figure 2.4: PMMP Flowchart

2.6.0. Information Quality Levels and Information Groups

As the management process moves from planning, through programming and preparation to operations, the amount of data detail required increases progressively in intensity, this feature can be used to assist the data design process by combining the functional levels of highway management with information quality levels (IQL). These provide a standardised definition of the level of detail of different data items, such that they are of a consistent accuracy for different functions (Robinson, 1995).

Appropriate and up-to-date information and data sits at the heart of the management cycle (Figure 2.2) and every PMMS. According to Robinson *et al.* (1998), these are some information groups: Road inventory (network, geometry, furniture), Traffic (volume, loadings & accidents), Pavement (structure & condition), Structures (inventory & condition), Finance (costs, budget & revenue), Activities (projects, treatments & commitments), Resources (personnel, materials & equipment)

Figure 2.6 shows the Road Information Management Systems (RIMS) Group Data Model and Content Guide explaining the Model of RIMS Data Groups, used in Australia. Models of this type have been used for asset management systems in the United States of America, Australia and Canada (Burns *et al.*, 1999).

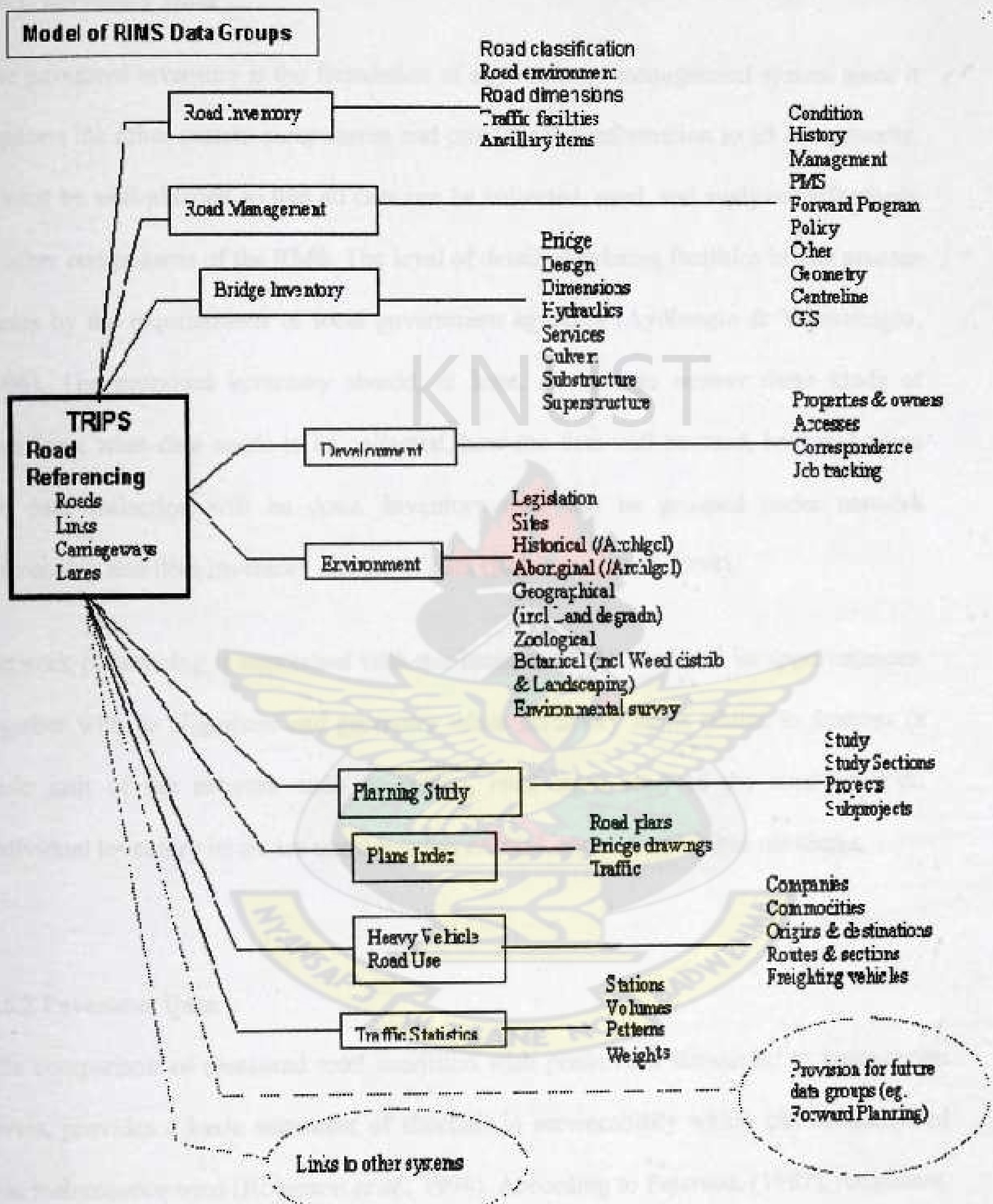

Figure 2.5 RIMS Data Model

Source: Department of Infrastructure, Energy and Resources, Road Information Management System.

2.6.1. Inventory Data

The pavement inventory is the foundation of any roadway management system since it supports the other system components and provides the information to all components. It must be well planned so that all data can be collected, used, and analyzed effectively in other components of the RMS. The level of detail of existing facilities in this process varies by the requirements of local government agencies (Aydinoglu & Yomralioglu, 2006). The proposed inventory should, at least, be able to answer these kinds of questions: what data needs to be collected, how the data will be used, how and when the data collection will be done. Inventory data can be grouped under network referencing and item inventory classes of data (Robinson, *et al*, 1998).

Network referencing is concerned with the location of the road and its appurtenances, together with its alignment and geometry while inventory items relates to *features* (a basic unit of the network such as bridge, road signs etc.) of the road network. Individual inventory items are considered as *entities*, each of which has *attributes*.

2.6.2 Pavement Data

The comparison of measured road condition with predefined standards, or intervention levels, provides a basic statement of shortfall in serviceability which can be translated into maintenance need (Robinson *et al.*, 1998). According to Paterson, (1987), roughness, surface distress, structural capacity, pavement texture and friction are parameters for assessment of pavement condition. These are assessed using condition surveys. Distress is one of the most important factors that influence the performance of pavements and these are measured during condition surveys. A variety of pavement distress can occur due to different causes such as load application, materials, environmental problems, etc.

Huang (1993), recommends that each type of distress be treated separately by developing a different application depending on the cause of distress. Pavement distresses reviewed for different pavement types are in Appendix A (Hass *et al*, 1994) and (GHA-MOM, 2001)

2.7 Database Design

The most efficient and flexible structure for a highway management system software is one which is modularised, with integration achieved through a common data bank. This modular structure must reflect the manual operation of the highway management process when broken down into functions and tasks. Many proprietary systems lack this modularity and are only available as a complete system, with a resulting loss in flexibility and ability to match the physical management structure (Robinson, 1995). With modular software, the information system (data bank) provides the back-bone of the management system. This comprises the network referencing system around which is built an inventory of the network providing the framework within which all information about, or associated with, the network are stored and retrieved. The software for this must be flexible enough to accommodate future changes and growth. This approach represents an ideal situation and does have long-term benefits. Different parts of the system can be developed independently, at different times depending on the resources available, using different software products. The disadvantages are that considerations of the long-term will be dictating short-term actions, with the result that the initial solution may be more expensive and complicated than a dedicated application.

Remembering that the most expensive component of the highway management system is the data, the key issue is to have the potential for upgrading the system in the future and still to be able to utilize data collected in the past. There will be many benefits when introducing systems for the first time to adopt a very simple approach in keeping with the institutional capacity of the highway authority. As operation and use of the simple system becomes institutionalized, and as technology advances, the system can be replaced. Provided the original system utilizes a database, it is a relatively straightforward exercise to download the data from the original system and to load it up into the new one. Such an approach may be more in keeping up with institutional development requirements whilst, at the same time, protecting the authority's investment in data.

Database design is executed, depending on user requirements (Aydinoglu & Yomralioglu, 2006). The approach used by an agency is dependent on the availability of information to support the development of the required models, the overall objectives for the analysis of the maintenance treatments, and the sophistication of the pavement management system (Zimmerman & Peshkin, 2003). A planning process is executed about what kind and quality of data should be involved in such a system. Figure 2.6 (GEOMATICA 5, 2003) shows the database design for Trabzon city of Black Sea Region, Turkey. Data collected were for city planning, land use, topography, cadastral, agricultural, and forestry data.. Spatial Data Infrastructure was built for Trabzon city structure including a variety of data.

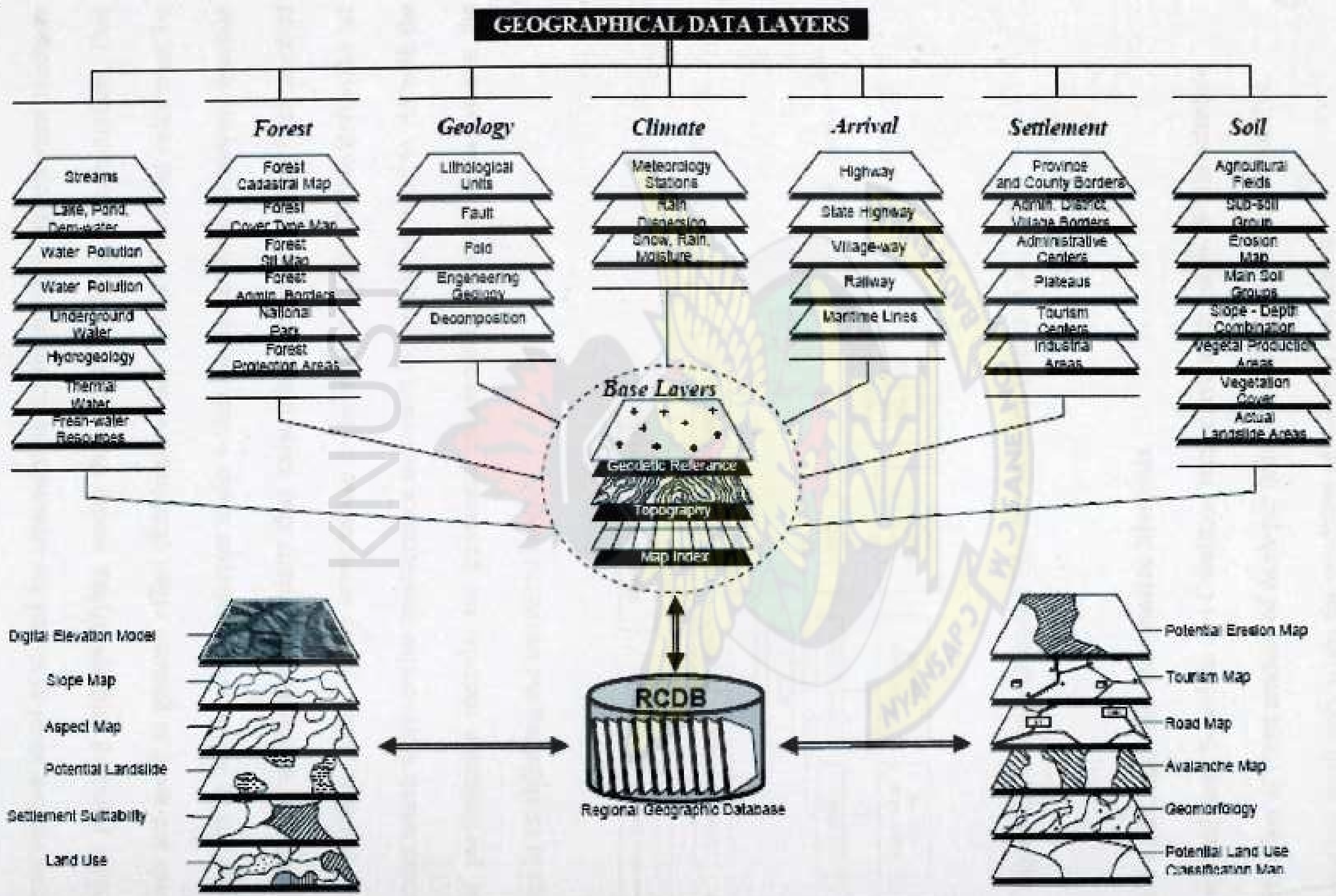

Image. 2: Cartographic design of Regional Spatial Database [7]

Figure 2.6 Cartographic design of a Regional Spatial Database

2.8. Pavement Treatment Selection

Standard and intervention level specified for treatment selection ensures that constant methods are observed when planning and specifying works throughout the Road Administration. This ensures that funds are spent to greatest effect (Robinson *et al.*, 1998,). Treatment rules must be developed by agencies to indicate the conditions under which the treatment is considered feasible and the reset rules that define the conditions that exist after the treatment has been applied (Zimmerman and Peshkin, 2003). Many agencies use decision trees (Figure 2.7) to define the set of conditions under which a preventive maintenance treatment is considered feasible. As with the development of performance models, the pavement management database must contain the information used in establishing the treatment rules.

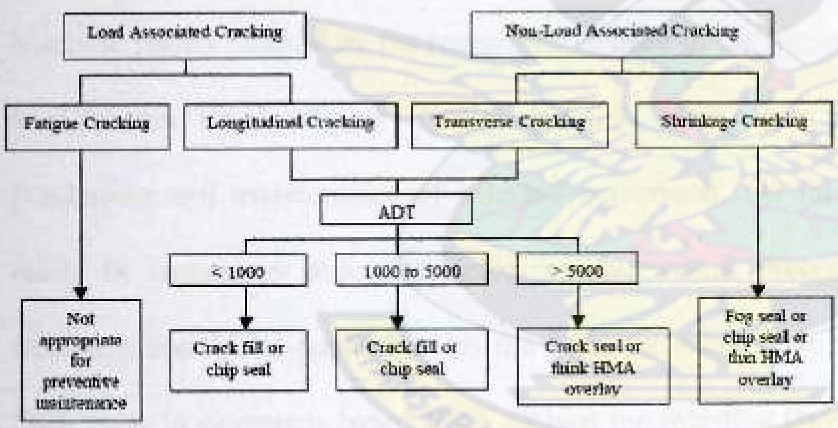

Figure 2.7 Sample Decision Tree for cracking (Hicks et al., 1997).

2.8.1 Schedule and Condition-Responsive Methods

Two methods studied were Schedule and Condition responsive approaches. While schedule relates to specification of fixed amount of work per unit time period, condition responsive, considers carrying out work only when the condition of the road reaches an intervention level. Due to the insufficiency of funds for road maintenance in developing countries (Zimmerman *et al.*, 1988) the condition responsive approach was discovered as in operation in Ghana.

Some routine treatment frequencies in a scheduled approach treatment selection such as grass cutting, cleaning of drains, cleaning of culverts are worth considering in a developing country PMS. Condition – Responsive treatment selection types considered in the study were, defect based rules, condition index-based rules and complex rules.

2.8.2 Common Features among Treatment Selection Approaches

Common to these selection types were methods of defect assessment, precedence rules and sectioning. On methods of defect assessment, manual measurement was preferred to Machine Based Method by the researcher as used in the Morogoro Roads support project in Tanzania Road Mentor System (OECD, 1995) due to inadequate funding for purchasing and maintenance of selected equipment. On the other hand, people could easily be trained to undertake defect measurements. Precedence rules identify which treatment should be applied when the need for more than one treatment is identified. Such rules in computer based PMS replace the intuitive knowledge of the Maintenance Engineer making the knowledge and decision of the Maintenance Engineer accessible to all stakeholders in the road sector. Some of the outputs of precedence rules in PMS in the Tropics discovered were: full pavement reconstruction, inlay, dense graded asphalt overlay, thin overlay, single surface dressing, patching, crack sealing. To make the system less sophisticated, algorithms are written to combine short defect lengths into longer sections of road of a minimum length to enable appropriate treatments to be applied in a more cost – effective manner (Robinson *et al.*, 1998).

2.8.3 Defect – Based Rules

These methods make use of a matrix of relationships between measured defects (Robinson *et al.*, 1998). A particular treatment is triggered if one or more defects exceed their programmed intervention levels. It makes used of logical (AND, if or OR) relationships to combine defects.

2.8.4 Rules based on Condition Indices

Condition indices combine defects into groups using functional relationships for treatment selection purposes. They provide a convenient grouping of defects and an interim step in a calculation or algorithm for determining treatments and a generic statement about defectiveness. Paterson, (1987) noted condition indices approach being helpful since most treatments can be seen to be correcting one or more of the four defect groups.

2.8.5 Complex rule approaches

These comprise non-transparent methods and expert supplement which give results consistent with engineering expectations but the method of operation is difficult to follow manually. (Figure 2.8)

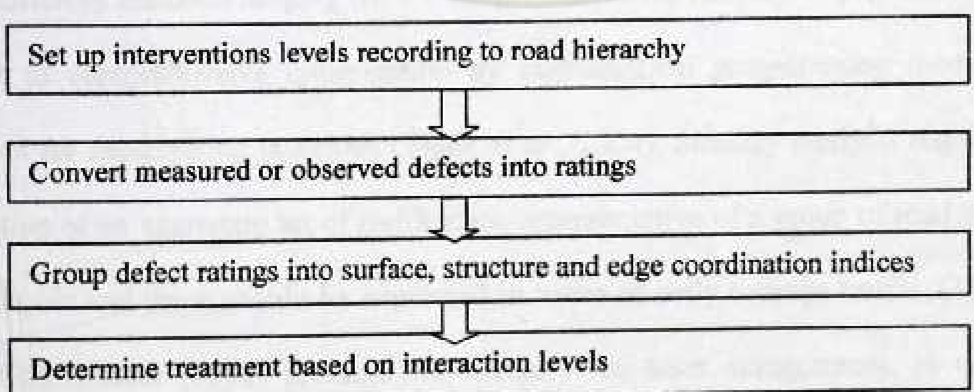

Figure 2.8 UKPMS treatment selection process

2.8.6 Treatment selection Approaches for Gravel Roads

Defect parameters often discovered on gravel roads are roughness, surface distress, structural adequacy and dust treatment selection methods considered were: routine - filling, grading :(heavy grading, light grading or dragging and dust control), and periodic (overlay) –regravelling options are available as remedial treatment alternatives. Robinson et al (1998) citing Millard, (1993), put forward that dust is controlled by the application of water, deliquescent salt calcium chloride, organic compounds; (eg. sulphite liquour, molasses, palm and other vegetable oil or mineral oils, such as waste fuel oils).

2.9 Prioritization

A common feature is that any prioritization of maintenance projects is concerned only with the forthcoming financial year and is based upon budget allocation arising from the network view (Tillotson et. al., 1998). Prioritization becomes an effective tool for supporting decisions to be taken for effective pavement management as the road management system strives to achieve the maximum benefits (Tighe *et al.*, 2004).

Depending on the funding levels, location, and specific conditions of a transportation agency, different methods ranging from a simple subjective ranking of projects based on judgment to comprehensive optimization by mathematical programming models, are being used for determining priorities (Tighe *et al.*, 2004). Strategy analysis requires the specification of an aggregate set of traffic data, representative of a group of road sections in the analysis and these should be expressed in terms of daily average traffic. (Tillotson et al, 1998). Vanier (1999) presents six "What's" of asset management, in order of priority: What do you own?, what is its worth?, what is its condition?, what is the remaining service life?, what is the maintenance backlog?, what will you fix first?

Typically most organizations fare well for the first two questions, then may fail miserably on the remaining four questions. Or, there might be a scattering of responses depending on the domain (i.e. roadways, bridges, parks or buildings).

Decision support systems have evolved over time and had become more sophisticated in a bid to solve these questions through the way they; subdivide the road network into sections, use intervention levels to determine treatments, enable the analysis of different numbers of treatment options per section, carry out economic analysis and prioritize decision when there are budget constraints (1st, 2nd, or 3rd generations' prioritization approaches) (Appendix E4). In the analysis of the systems, 1st generation systems approach could best suit the scope of this research but in the section of treatment options, 2nd generation approach of do something and do minimum for each section may be considered. 1st generation systems considers fixed lengths of sections, bases intervention levels on present pavement condition, undertakes economic analysis based on present cost of treatment and ranking is based on function of present costs, condition and road hierarchy.

Analytical Hierarchy Process (AHP), (Saaty, 1979), is another prioritization approach. Analytical Hierarchy Process (AHP) used for road management system in Champaign by Chavarria (2002) which used a lot of factors to come up with an optimum decision was evaluated and considered in this system. It confirmed the assertion of Sadek *et al* (2003), that 'earlier management systems were typically developed to manage individual components of the transportation system but more recently, these systems have been evolving into integrated infrastructure management systems (IIMSs) that simultaneously consider the needs of the different components of the entire transportation system'. The general factors considered in top levels (Figure 2.9) and detail factors are compared and assessed in lower levels and finally values were assigned for different factors from top to the bottom levels.

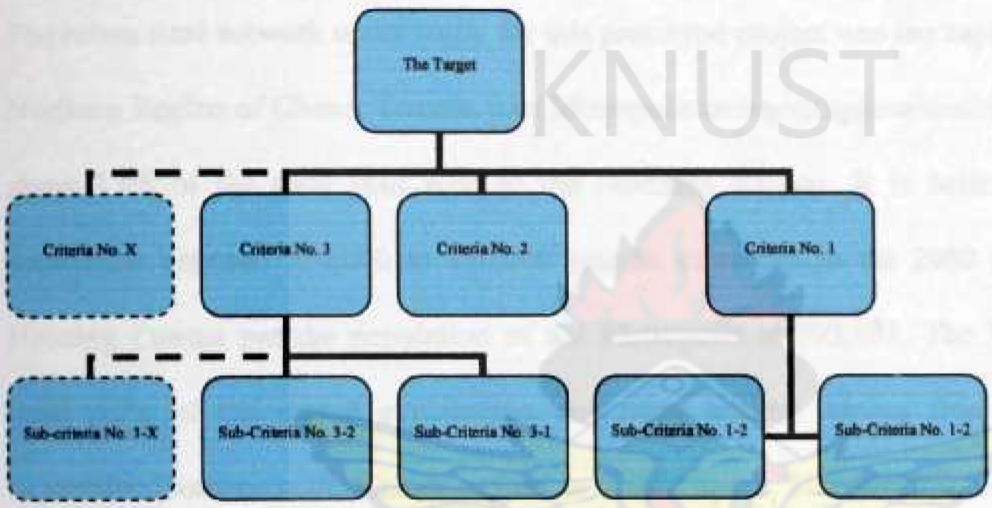

Figure 2.9. Analytical Hierarchy Process (AHP)

Based on the above chart the model uses the following function to combine the criteria:

$$F=k_1X_1 + k_2X_2 + k_3X_3 + \ldots\ldots\ldots + k_nX_n$$

In which K_1, K_2 and K_3 ....K_n, are the coefficients for X_1, X_2 and X_3 criteria respectively and are determined by professional personnel who are involved in road construction planning in the area. Other parameters outlined in Appendix E1 could be considered to provide the hierarchical tree structures of the criteria.

Setting priorities for treatments to gravel roads are not different from paved roads in principle except that where scheduled treatment are used (e.g., for grading) frequencies of grading will need to be scheduled to match the budget level available for this activity.

Otherwise where budget allocation for maintenance is for both paved and gravel roads, they can be considered within the same prioritization process for paved roads (Robinson et al., 1998).

2.10 Area for the Study

The urban road network under study for this prototype project was the capital town of the Northern Region of Ghana, Tamale. The Metropolis occupies approximately 750km sq., about 13% of the total land area of the Northern Region. It is believed to have a population between 350,000 to 450,000 people, even though the 2000 population and Housing Census put the population of the Metropolis at 293,881. The Metropolis like most parts of the region experiences one rainy season starting from April/May to September/October with a peak season in July/August. The Metropolis experiences a mean annual rainfall of 1100mm within 95 days of intense rainfall. The Metropolis is located approximately 180 metres above sea level. (Constructs LLC, 2006)

This is a metropolitan area undergoing extensive development in terms of infrastructure, agriculture, security, tourism, education and freight movement. Maps showing population density, roads in Ghana with population density, urban areas in Ghana and Tamale road network are shown in Appendix D.

2.11 Integration of PMS with Geographical Information Systems

Many factors have led GIS to be accepted as a decision making tool. Environment management for decision making and future planning is a current topic in global and regional works all over the World. Constructing Spatial Data Infrastructure in wide extended areas provides many opportunities for controlling natural resources and environmental changes (Aydinoglu & Yomralioglu, 2002).

Road management system with a GIS platform to evaluate maintenance needs as did Niaraki (2003), Peded *et al*. (1993) and Prasad *et al*. (2003) who considered in addition, road traffic, tourist sites, security base and checkpoints, climate, human and vehicle factors for their analysis and system developments is of much essence.

The most advanced computer based information technology tool for spatial planning is the Geographic Information System, which would become indispensable in planning and management of databases (Sonnen, 2005). GIS has the ability to analyze pavement management data based upon geographical location, display results of database queries and asset management analyses on a map, view asset conditions and projected work programs on a road map, view asset conditions across other geo-referenced information such as traffic, neighborhood soil conditions, zoning, make relevant data more accessible to the politicians, the public, and municipal administration (Aydinoglu & Yomralioglu, 2002)

A spatial decision support system (SDSS) provides a GIS linked DSS in which the spatial dimension of the data is fundamental to the analysis of decisions. Spatial decision support relies heavily on maps, which form the backbone upon which plans and policies are defined (Aydinoglu and Yomralioglu, 2002).

Problems can roughly be classified into siting and spatial allocation. In the first case, the main issue is determining the location, whereas in the latter, the unknown is the object itself. Some problems may require combination of both characteristics. Environmental planning, furthermore, involves studies of risk assessment, and contingency planning, which combine WHAT and WHERE to WHEN and HOW (Seffino *et al* 1999). Spatial decision making has traditionally been associated with the use of GIS. Muller, (1993) identifies SDSS as a growth area in the application of GIS technology. GIS products are increasingly available on inexpensive personal computers and the possibility exists of developing a SDSS to be used on relatively inexpensive equipment with which potential users can be familiar (Yomralioglu, 2000). The growth of SDSS applications is also made possible by the growing availability of spatial data for popular GIS software, thereby reducing the costs of data collection (Keenan, 1998).

A number of commercially available GIS software packages are available; however, the basic structure of a GIS remains the same from program to program (Anil *et al*, 2003); Geographical database, Attribute database and Geo-relational data structure.

2.12 System Development

The output of the system determines the input and the processing (Schneider, 1999). A program development cycle and a sequence of planned steps need to be outlined to reduce the number of mistakes and time spent working on the program (Schneider, 1999) Ben Shneiderman's "Eight Golden Rules of Interface Design" (Shneiderman, 1997) (Appendix E8) and Chapple's Databases Blog citing Codd's 12 Rules underpinnings modern Relational Database Design (Appendix E9) were carefully considered.

Additionally, a step-by-step procedure ought to be reviewed to facilitate the design of an error-free program;

Analyze: This is defining the problem; understanding what the program was to do, that is, what the output should be and have a clear idea of what data (or input) are required and the relationship between the input and the desired output.

Design: The solution of the problem is then planned. An algorithm, a logical sequence of precise steps that solve the problem is thought out. Three methods for the development of the logic plan were flowcharts, pseudocode, and top-down charts. The flowchart method provides a pictorial representation of the task, which makes the logic easier to follow. How each step is connected to the next could clearly be seen. Representative data is used to test the logic of the algorithm by hand to ensure that it is correct.

Choice of interface: This is the selection of the objects (text boxes, command buttons, etc.) to determine how the input is be obtained and how the output will be displayed. Objects are created to receive the input and display the output as well as appropriate command buttons to allow the user to control the program.

Coding (writing the program)*:* this involves translation of the algorithm into a programming language.

Data Validation: Data validation procedures are imperative before data analysis begins. Not all data that has traditionally been collected are significant (Wilson et al, 2002) or realized as important and so the data need to be well sorted to evade its effect on the modeling output accuracy.

Testing and debugging: This is the location and correction of any errors in the program.

Documentation: This is the organization of all the material that described the program. Documentation is intended to allow users to understand the program. It encompassed a detailed description of what the program does and how to use it.

Chapter III

METHODOLOGY

3.1. Desk Study

The areas of interest were asset management, integrated management systems, road maintenance management systems, global information systems; road management based global information systems and other relevant materials. The sources of these literatures were the internet, published journals and books, lecture notes, conferences and seminars.

3.2. Area for the Study

The urban road network considered for this project was the capital town of the Northern Region of Ghana, Tamale. This is a metropolitan area undergoing extensive development in terms of infrastructure, agriculture, security, tourism, education and freight movement.

3.3. Data Collection

Data was collected on the Tamale road network in 2004/2005 through a Road Condition Survey. Oral interviews were also conducted and questionnaires were also administered to road users and some engineers at the road policy implementing agencies in Ghana (Ghana Highway Authority, Department of Urban Roads and Department of Feeder Roads) on their perception and destructive importance attached to different road defects, their cost of repair, and the discomfort to motorists. This culminated in their assigning of weights to these pavement defects which were further evaluated to establish a sound bases for the PCI evaluation.

3.3.1. Road Condition Survey

There were two survey teams for the road network survey and the researcher was a team leader and rater in one of the teams. Each consisted of one principal precimeter driver and two Engineers who were raters. The survey teams were taken through what were expected of them during the road condition survey. Some of these were their ability to recognize pavement distresses, inventory items, estimation of distances and area, legible recordings on data forms, map reading skills, how to avoid accidents during the exercise among others. The data collection was done in two phases. The main data collection was undertaken from 18th December, 2004 to 2nd January, 2005 and 15th-29th January 2005. The second which was a mop-up was conducted from 3rd -13th June 2005. An A0 sheet size map of the Tamale road network which had all the link numbers of the roads were used to identify the links on the ground. The entire network was sectioned into zones. Data was collected on links within zones every day over the period of the survey. About 10-20 km of roads were surveyed in a day except where there were obstructions such as ill-health of a team member, rains or an interaction with the staff of the urban roads department for some clarity. The data collected comprised the roads definition, road inventory and road condition and NMT lanes. On methods of defect assessment, manual measurement was used. The Department of Urban Roads condition and appurtenance survey forms (Appendix C) for paved roads and gravel roads were used for data recordings of the surveys. Guidelines for identification, measurement and rating of each data item which were used were according to guidelines on data collection prepared by the World Bank (Paterson and Scullion, 1990) and (Huang, 2004). The data collection was followed by data entry into MS Excel 2003 and then imported to MS Access 2003.

3.3.1.1 Road Definition

To define the visual nature of every road link, the road number (Major arterial, minor arterial, collector and local roads (A, B, C and D class roads respectively) the road name (if any), number of segments (1, 2, 3 or 4), the length (m), lane count (1, 2, 3 or 4), road width (m), surface class (paved and unpaved road)and pavement types (asphalt concrete, double surface dressing, single surface dressing, were noted and measured appropriately. The road link reference format used for the survey was similar to that used in the HDM-4 and the Department of Urban Roads in Ghana.

It could be generalized as AA-BB-C-DDDD-EEE where;

AA represents the Metro or Municipal Area Code,

BB represents the Sub-Zone Code

C represents the Road Class

DDDD represents the Road Number and

EEE represents the Link Number

Table 3.1 is a Tabular representation of how Data on road definition was recorded

Table 3.1 Road Definition Data Sheet

Road No	ROAD NAME	LINK NO	SEGMENT NO.	START	END	LANE COUNT	WIDTH (m)	SURFACE CLASS	PAVEMENT CLASS	COMMENT

3.3.1.2 Road Inventory

Corresponding to every road link defined, the length (m), width (m), diameter (m), condition (excellent, very good, good, fair, poor, and very poor), shape, orientation (Left, Right and Middle) and condition of their respective inventories were taken where applicable. The inventories included drains, culverts shoulder, road marks, curbs, electric poles, telephone poles, trees, lay-byes, traffic lights, road sign etc.

Table 3.2 is a Tabular representation of how Data on road inventories were recorded

Table 3.2 Road Inventory Data Sheet

Road No	Road Name	Link No.	Segment No.	Item No. Feature	Start	End	Type	Surface Type	Shape	Width (m)	DIAM (m)	Orient	Condition	Remarks

3.3.1.3 Road Defects

The type of defects on each of the road links were also determined and measured. The kinds of defects assessed were alligator cracks, longitudinal cracks, transverse cracks, ruts, bleeding, corrugation, depression, patch deterioration, potholes, raveling and shoving, edge step, edge break etc The chainages, width, depth, location and orientation were measured to determine the extent of occurrence and severity of defects. The details of the measurement of the severity and extent of occurrence of these defects are in Appendix A. Table 3.3 is a Tabular representation of how Data on road defects were recorded

Table 3.3 Road Defects Data Sheet

Road No	Road Name	Link No.	Segment No.	Defect No.	Defect Type	Start	End	Length (m)	Width (m)	Side	Depth (m)	Remarks

3.3.1.4 Non-Motorable Transport (NMT) Lanes

To define the visual nature of NMT lanes, the road number (Major arterial, minor arterial, collector and local roads (A, B, C and D class roads respectively) the road name (if any), number of segments (1, 2, 3 or 4), the length (m) (Start and end), lane count (1, 2, 3 or 4), pavement types (asphalt concrete, double surface dressing, single surface dressing, gravel or earth), the width (m) orientations, condition and any remarks were noted and measured appropriately. Table 3.4 presents the above information as per for the take offs during the road condition survey.

Table 3.4 NMT Lane Sheet

Road No	Road Name	Link No.	Segment No.	Start	End	Length (m)	Width (m)	Orientation	Condition	Remarks

3.4. Database Development

A modular structure was used in the design of this system to enable individual components to be implemented in a phased programme (Tillotson *et. al.*, 1998).

Two main kinds of data were used: spatial (the digital Tamale road network map) and non-spatial data (the Tamale road condition survey data) (Figure 3.1). The road data collected during the RCS was used to update a digitized road map database. It was also used to build an MS Access 2003 database to serve as the databank for the decision support system, which was responsible for defect evaluation, appropriate treatment recommendation and prioritization.

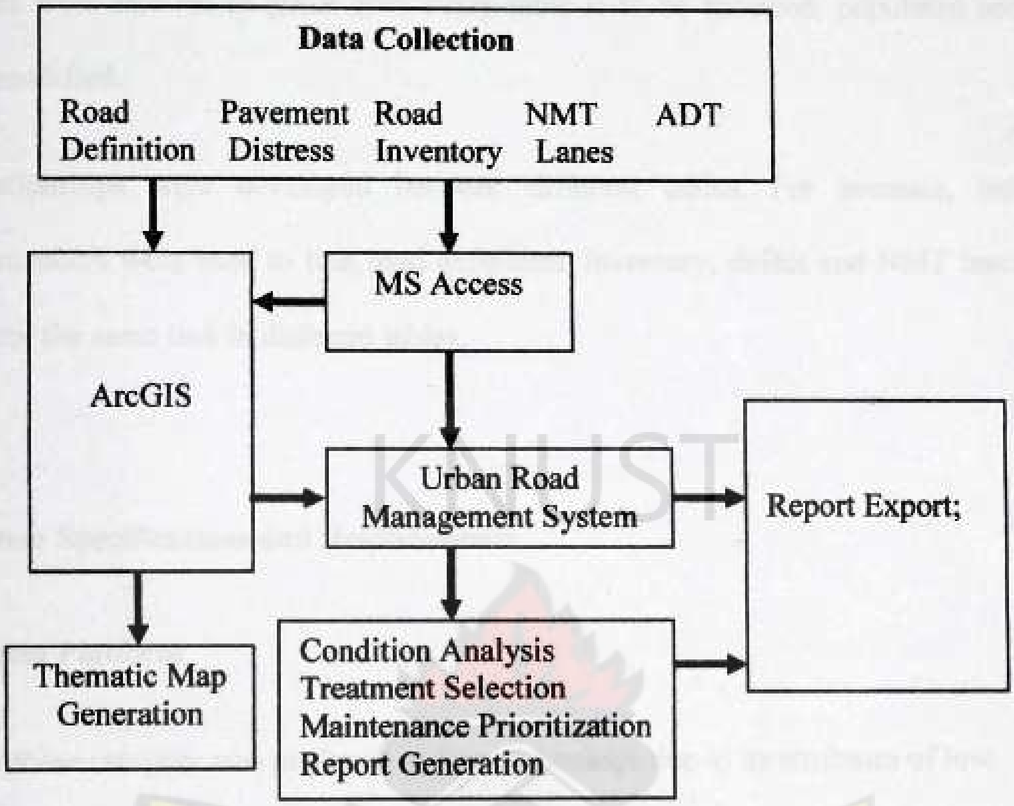

Figure 3.1: Flow Chart for Development of the Urban Road Management System (URMS)

In the design of the framework for the database, these step-by-step processes was followed;

i. Information required for the design of the database were sought

ii. Entities and attributes on which data was collected were used to develop table headings and workbooks. The columns in the tables were the attributes while the rows constituted the specific occurrence of entities.

iii. An attribute (primary key) was then selected which uniquely identified an object. The primary key checks data and prevents data duplication.

iv. Rules were also set to guide how every table is to be accessed, populated and modified.

v. Relationships were developed between different tables. For instance, link numbers were used to link road definition, inventory, defect and NMT lanes for the same link in different tables.

3.5 System Specifications and Requirements

3.5.1 System Platform

Desktop database category was preferred to Server database due to its attributes of low cost, ability to run on low specification computers and widespread use simplicity of use. It is one of the basic MS Office software applications which almost every personal computer with MS Office suite is likely to have. MS Access 2003 of MS Office suite 2003® was used to as the main system database platform due to its extensive use in Ghana. ArcGIS 9.2 was selected as the platform for the spatial database due to its advanced features, current worldwide use and ability to access data directly from MS Excel.

3.5.2 Programming Language

The programming language selected for the system development was Visual Basic.Net. Visual Basic Applications in ArcGIS was the most ideal of all because it had already been built into the ArcGIS software which solves all linkage problems which normally arise due to incompatibility of languages but had much rigidity in terms of use and poor

Graphical User Interface (GUI) design features compared to Visual Basic.Net 2005 (vb.net). Vb.net 2005 however links is always seeing upgrades, has a broad base use and has easily accessible audio and video training tutorials for personnel development. Trainers to train personnel in vb.net can also be reached.

3.5.3 Hardware Requirements

This system for requires the following:

Intel Pentium III 400MHz class processor (P III 933MHz or higher recommended), Microsoft Windows 2000 with Service Pack 2 (SP2), Windows XP Professional or Home Edition with SP2, or Vista, 128 MB of installed RAM (512 MB recommended), 5 GB of available hard disk space; optional installation files cache (10GB recommended) requires an additional 300 MB of available hard disk space Minimum of 800 x 600 screen resolution, CD-ROM drive, if installing from a CD or a USB port in the case of an external hard disk or a pen drive.

3.6 Data Validation

Methods used to ensure the output accuracy were a mop-up data collection exercise to fill up missing but relevant and uncollected data (Wilson *et al.*, 2002). Data was well sorted out into classes to help track errors. Manual computations were carried out and compared with the output of the system to ensure consistency in results. Primary keys were also assigned to ensure data uniqueness to particular links

3.7 Program Planning

A program development cycle and a sequence of planned steps were outlined to reduce the number of mistakes and time spent working on the program (Schneider, 1999) and the step-by-step process discussed in Section 2.11 was adopted to help design an error-free programs that was expected to produce the desired output with considerations of Ben Shneiderman's "Eight Golden Rules of Interface Design" (Shneiderman, 1997) (Appendix E5)

3.8 Condition Analysis and Treatment Selection

The condition indices approach was used in this study (Section 2.8.4) Paterson, (1987) noted this approach being helpful since most treatments can be seen to be correcting one or more defect groups. Some index based methods evaluated were; Present Serviceability Index (PSI), International Roughness Index (IRI), and Riding Quality and Pavement Condition Index (PCI) (Anil & Prapoon, 2003). Of these PCI was selected due to its simplicity and widespread use (Tighe *et al.*, 2004).

A questionnaire (Appendix A1) was administered to road users and engineers most of whom were road maintenance engineers at the road policy implementing agencies in Ghana. These Agencies were the Ghana Highway Authority, the Department of Urban roads and the Department of Feeder roads. The questionnaire was to get their perception of the damaging effects of different defects, their consequence road user cost, cost of rehabilitation and the level of riding discomfort these cause to road users. Weights were expected to be assigned to these defects based on these factors. A weight range of 1, 2, 3 or 4 were expected to be assigned to these defects. Weight 4 warrants the most urgent treatment, the incurring of most cost of rehabilitation, highest road user cost and causing the most discomfort to road users making the road worst in safety to motorists. Weight 1 warrants comparatively the least of the factors outlined for weight 4. These weights per defect obtained from the answers to the questionnaire were summed and the averages were found for respective defects.

Data on the cost of correction or rehabilitation of various defects were also obtained from the Department of Feeder Roads and the Department of Urban Roads for a critical evaluation of weights to be assigned to these defects. These were geared towards the development of a customized condition rating form (Appendix E4) pertaining to prevailing conditions and factors for condition analysis in Ghana.

Calculation of the PCI was based on the results of the visual road condition survey in which distress type, severity, and extent of occurrence are identified. The PCI number (0-100) reflected the structural integrity and surface condition of the pavement. The PCI expression was appropriated to reflect the situation in Ghana with respect to the ratings and weights of defects through answered questionnaire administered to the road implementing agency Engineers. PCI ranged from 0 for a failed pavement to 100 for a pavement in perfect condition. The reviewed mathematical expression for PCI used in this thesis is shown as follows:

$PCI = (20(5.00-1/20\sum(R x W))$

Where R=rating and W=weights with respect to cost of repair of respective defects.

3.9 Prioritization

The factors considered when priorities were assigned were; deterioration index (in this case PCI), traffic, branch use, and pavement rank (class 'A', 'B', 'C' or 'D') and some parametric factors in Appendix E1 (Tighe *et al.*, 2004). Analytical Hierarchy Process (AHP), (Saaty, 1979), was also considered.

The road sections were prioritized for rehabilitation using a priority formula where the highest score indicates the highest priority. This formula is similar to that used in the Pavement Maintenance and Management Programme (PMMP) by the Ghana Highway Authority. Some factors outlined in Appendix E1 to reflect the Road Prioritization Methodology (RPM) being used by the DFR were considered. In RPM the people have a say in which road are of more importance than others and hence require quicker attention and this is an illustration of the AHP. The priority formula for paved roads:

$$\text{Priority Formula} = \frac{[(\text{Class Factor}) \times (\text{ADT Factor}) \times 1000]}{\text{Condition Factor}} + \text{Economic Factors}$$

Where Class Factor = 2.0 for Major Arterials (Class 'A')

1.5 for Minor Arterials (Class 'B')

1.25 for Collector Roads (Class 'C')

1.0 for Local Roads (Class 'D')

ADT Factor = $(ADT/500)^{0.1}$, where ADT is set to 500 if unknown or less than 500

Condition Factor = $10^{(PCI/100)}$

Economic Factors comprise Markets, Customhouse, Industry (industrial suburbs, units and storage points, Agriculture: (irrigation networks, fisheries, food and animal producing centres, stakeholder centres, dams etc that add on to the importance of these roads (Appendix E1). These are noted during the data entry and assigned a point of five (5) each.

For unpaved (gravel) roads, the formula was factored by 0.5 and an ADT of 50 is used if unknown or less than 50. The formula then becomes:

$$\text{Priority Formula} = \frac{0.5[(\text{Class Factor}) \times (\text{ADT Factor}) \times 1000]}{\text{Condition Factor}} + \text{Economic Factors}$$

3.10 User Feedback

A Graphical User Interface (GUI) was used on the forms which display features of the system. When a user sends a query, the system processes it and responds accordingly as per defined codes. Each argument and value pair is referred to a query parameter. Arguments transmit the information to the application which function is executed by the system.

3.11 System Testing and Packaging

The software was run on a number of computers to ensure the output was consistent and reports were printed out as well as exported to other systems for further analysis. It was then written unto a compact disc which could be accessed with due permission. A user may have to install the software on his computer to benefit from the opportunities that it brings.

CHAPTER IV

DISCUSSIONS ON SYSTEM

4.1 The System

This system comprises a digital Tamale road network map, a road definition, inventory, NMT lane information and pavement decision support module (Figure 4.1). The system has a spatial database in ArcGIS, an MS Access non-spatial database, with a Visual Basic.Net interface placed in a WINDOWS environment for ease of use by different categories of users.

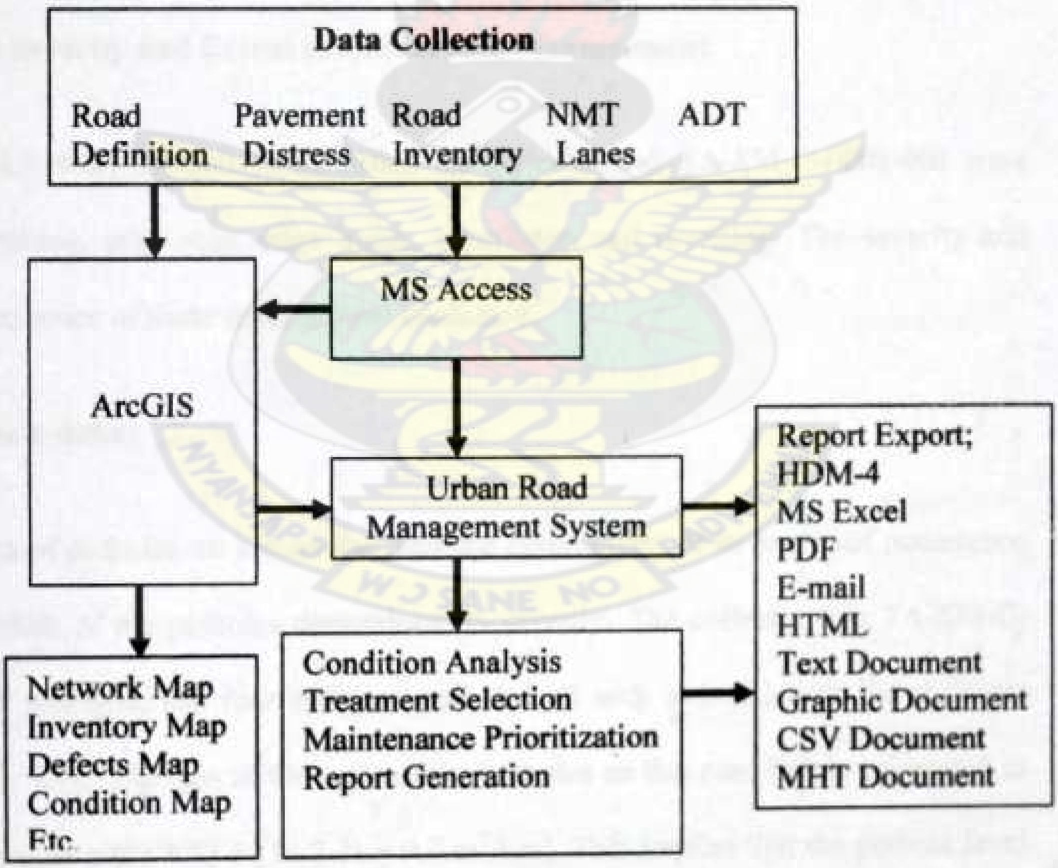

Figure 4.1 Detailed Flowchart of System

4.2. Illustration of system: A case study of road link TA-SM-C-0001-001

A Collector road TA-SM-C-0001-001 was used to illustrate the system. Table 4.1, 4.2, 4.3 and 4.4 were its survey data for road definition, inventory, defects and NMT lanes for different links respectively. TA-SM-C-0001-001 was 862 m in length, 7.4 m two lane and single surface bituminous road. The inventories on the road were a concrete U-drain along both sides of the road and kerbs at a number of chainages along the road. The defects were potholes, patching, edge step, edge break, depression, ravelling and their respective places of location, length, width, orientation are in Table 4.3. These were measured according to the specifications in appendix A (MOM-GHA, 2001)

4.2.1. Defect Severity and Extent of Occurrence Measurement

As in table 4.3, the road defects identified for collector link TA-SM-C-0001-001 were potholes, patching, edge step, edge break, depression and ravelling. The severity and extent of occurrence of these defects were evaluated.

4.2.1.1. Pothole defect

The total area of potholes on a road link was the determinant of its extent of occurrence whiles the width of the potholes determined its severity. The collector link TA-SM-C-0001-001 for example, has four different potholes all with a 1 m length but different widths (Table 4.3). The sum of the areas of the potholes on this road link is calculated as [(1x 4) + (1x 0.6) + (1x 0.8) + (1x 3.3) = 9.7 m^2/km]. This implies that the pothole level for collector link TA-SM-C-0001-001 with a total pothole area of 9.7 m^2/km is a level one pothole and hence more localized in extent of occurrence (GHA-MOM, 2001).

According to Ghana Highway Authority Maintenance Operation Manual (GHA-MOM, 2001), pothole levels have been grouped into 4 different levels depending on the total area of coverage of the potholes per 1 Km of road. Pothole areas of below 10 m^2/km, between 10 m^2/km and 30 m^2/km, between 30 m^2/km and 50 m^2/km and above 50 m^2/km area referred to as level 1, level 2, level 3 and level 4 potholes respectively. Level 1 relates low in extent of occurrence in this system. Level 2 corresponds to intermittent while 3 and 4 corresponds to prevalent in extent of occurrence in this system.

4.2.1.2. Patching defect

Patching in table 4.3 were 5 in number, small and localized according to GHA-MOM, (2003). The severity level (slight, moderate and severe), slight implied patch has no sign of deterioration, moderate is somewhat deterioration and can be felt in the ride, while severe in is implied when patched areas are rough, coming apart and breaking up (Appendix A). The extent of occurrence was based on the area of patches for the road length. 1-15%, 16-30% and 30% and above of the road section prevalence of patches implied localized, intermittent and prevalent extents of occurrence respectively. Patchings on TA-SM-C-0001-001 were moderate in severity because they were somewhat deteriorated and required vehicular reduction in speed and localized in extent of occurrence (0.5%) having a total length of 4.7m.

Table 4.1 Road Definition of TA-SM-C-0001-001

ROAD NAME	LINK NO.	SEGMENT NO.	START	END	LANE COUNT	WIDTH	SURFACE CLASS	PAVEMENT CLASS	COMMENT
SOUTH LAMASHIEGU LINK ROAD	TA-SM-C-0001-001	1	0	862	2	7.4	B	SSD	
SOUTH LAMASHIEGU LINK ROAD	TA-SM-C-0001-002	1	0	423.5	2	7.4	B	SSD	

Table 4.2 Road Inventory of TA-SM-C-0001-001

d	Road Name	Link No.	Seg. No.	Item No.	Start	End	Type	Surface Type	Shape	Width	Diam	Orient	Feature	Condition	Remarks
001		TA -SM-C-0001-001		1	9.5	40.6	C		U	0.6		L	DRUCu	G	
001		TA -SM-C-0001-001		2	9.5	40.6	C		U	0.6		R	DRUCu	G	
001		TA -SM-C-0001-001		3	40.6	46.7	C		U	0.6		L	DRUCu	G	
001		TA -SM-C-0001-001		4	40.6	55.5	C		U	0.6		R	DRUCu	F	
001		TA -SM-C-0001-001		5	53.5	53.5	C		U	0.6		L	DRUCu	F	
001		TA -SM-C-0001-001		6	382.0	418.5						R	KB	G	
001		TA -SM-C-0001-001		7	422.2	429.5						R	KB	G	
001		TA -SM-C-0001-001		8	429.4	441.4						R	KB	G	
001		TA -SM-C-0001-001		9	446.0	466.0						R	KB	G	
001		TA -SM-C-0001-001		10	468.8	494.6						R	KB	G	
001		TA -SM-C-0001-001		11	498.5	523.9						R	KB	G	
001		TA -SM-C-0001-001		12	527.9	574.3						R	KB	G	
001		TA -SM-C-0001-001		13	50.2	58.4						R	KB	G	
001		TA -SM-C-0001-001		14	63.2	108.8						R	KB	G	
001		TA -SM-C-0001-001		15	113.5	138.7						R	KB	G	
001		TA -SM-C-0001-001		16	143.8	170.6						R	KB	G	
001		TA -SM-C-0001-001		17	175.1	189.8						R	KB	G	
001		TA -SM-C-0001-001		18	194.5	272.0						R	KB	G	
001		TA -SM-C-0001-001		19	278.2	322.7						R	KB	G	
001		TA -SM-C-0001-001		20	636.1	642.0						R	KB	G	
001		TA -SM-C-0001-001		21	644.0	677.2						R	KB	G	
001		TA -SM-C-0001-001		22	684.2	694.1						R	KB	G	
001		TA -SM-C-0001-001		23	699.5	704.9						R	KB	G	
001		TA -SM-C-0001-001		24	706.6	745.5						R	KB	G	
001		TA -SM-C-0001-001		25	751.0	789.3						R	KB	G	
001		TA -SM-C-0001-001		26	794.4	811.8						R	KB	G	

Table 4.3 Road Defects of TA-SM-C-0001-001

ad No	ROAD NAME	LINK NO.	SEGMENT NO.	DEFECT NO.	DEFECT TYPE	START	END	LENGTH	WIDTH	SIDE	DEPTH (mm)
0001		TA-SM-C-0001-001	1	1	PH	388.1	389.1	1	4		
0001		TA-SM-C-0001-001	1	2	PH	509.6	510.6	1	0.6		
0001		TA-SM-C-0001-001	1	3	PH	735.6	736.6	1	0.8		
0001		TA-SM-C-0001-001	1	4	PH	810.7	811.7	1	3.3		
0001		TA-SM-C-0001-001	1	5	PA	38.1	39.1	1	15		
0001		TA-SM-C-0001-001	1	6	PA	645.6	646.3	0.7	4.5		
0001		TA-SM-C-0001-001	1	7	PA	707.2	708.2	1	4.5		
0001		TA-SM-C-0001-001	1	8	PA	723.6	724.6	1	1.5		
0001		TA-SM-C-0001-001	1	9	PA	750.4	751.4	1	1.2		
0001		TA-SM-C-0001-001	1	10	ES	52.6	53.8	1.2	0.3	L	40
0001		TA-SM-C-0001-001	1	11	ES	359.4	364.3	4.9	0.2	L	60
0001		TA-SM-C-0001-001	1	12	ES	612.3	627.2	14.9	0.2	R	50
0001		TA-SM-C-0001-001	1	13	ES	744.4	746	1.6	0.3	R	30
0001		TA-SM-C-0001-001	1	14	ES	794.4	810.7	16.3	0.5	R	65
0001		TA-SM-C-0001-001	1	15	ES	815.8	857.5	41.7	0.4	R	55
0001		TA-SM-C-0001-001	1	16	EB	460.2	532.9	72.7	0.8	R	45
0001		TA-SM-C-0001-001	1	17	DP	142.4	143.2	0.8	7		50
0001		TA-SM-C-0001-001	1	18	DP	219.3	222.2	2.9	0.3		40
0001		TA-SM-C-0001-001	1	19	DP	500.5	598	97.5	0.4		30
0001		TA-SM-C-0001-001	1	20	DP	673.9	697.6	23.7	0.6		45
0001		TA-SM-C-0001-001	1	21	RA	52.6	73	20.4	1.5		

Table 4.4 NMT Lanes for a number of links

Road No.	Road Name	Link No.	Seg. No.	Start	End	Width	Orientation	Condition	Remark
0001	KUMASI ROAD	TA-SM-B-0001-006	1	5	91.1	2.7	R	G	
0001	KUMASI ROAD	TA-SM-B-0001-006	1	91.1	500.7	2.7	R	G	
0001	KUMASI ROAD	TA-SM-B-0001-015	1	0	23	2.7	R	A	
0001	KUMASI ROAD	TA-SM-B-0001-015	1	0	23	2.7	L	A	
0001	KUMASI ROAD	TA-SM-B-0001-016	2	381	406.4	3.1	L	A	
0002	LOUISEVILLE ROAD	TA-SM-B-0002-002	1	36.1	36.1	2	L	C	
0005		TA-SM-C-0005-004	1	0	215.7	1.5	L	C	
0005	St CHARLES-YAPEI ROAD	TA-SM-C-0005-004	1	0	215.7	1.5	R	C	
0005		TA-SM-C-0005-005	1	0	70.6	1.5	L	C	
0005		TA-SM-C-0005-005	1	0	70.6	1.5	R	C	
0005		TA-SM-C-0005-006	1	0	158.8	1.5	L	C	
0005		TA-SM-C-0005-006	1	0	158.8	1.5	R	C	
0012		TA-SM-C-0012-001	1	0	215	3.6	L	SD	
0012		TA-SM-C-0012-001	1	0	215	3.6	R	SD	
0012	NIM AVENUE ROAD	TA-SM-C-0012-001	1	67.4	205.5	4	L	SD	
0012	NIM AVENUE ROAD	TA-SM-C-0012-001	1	0	29.7	4	R	SD	

4.2.1.3. Edge Step / Break defect

The measurement of Edge Step / Break was very similar to patching in extent of occurrence as regards the percentages for the localized, intermittent and prevalent (Appendix A). For the severity, the most difference in prevalent severity level was rated. The elevational difference between the pavement and the shoulder determines the severity. 25-50mm, 50-100mm and above 100mm elevational differences refers to slight, moderate and severe respectively in severity ratings. The 7 defects of this type found on this link had elevational differences of 40, 60, 50, 30, 65, 55 and 45. The most prevalent ranged between 50 - 100mm making it moderate in severity. A summed length of 153.3m made it intermittent (16-30%) in extent of occurrence.

4.2.1.4. Depression defect

The total sectional length of pavement affected by depressions on a road link is the determinant of its extent of occurrence whiles the most prevalent depth of the depressions determine its severity. On link TA-SM-C-0001-001(table 4.3), four depressions were identified of depths 50, 40, 30 and 45 and these occurred over a stretch of 124.9m in length of the 862m total length of the road. This signifies about 15% of the total length. In the system therefore, depression on link TA-SM-C-0001-001 was moderate while extent of occurrence was intermittent.

Table 4.5: Damage Rating (R)

S E	1 Light	2 moderate	3 Severe
1 <15%	1	3	4
2 16-30%	2	4	5
3 >30%	3	5	5

4.2.1.5. Ravelling defect

Ravelling, also referred to as fretting from table 4.3, occurred only once. This defect refers to the wearing away of the pavement surface. Few pieces of aggregate visbly dislodged from the pavement and sitting on the road surface was graded as slight in severity. Moderate severity is selected when loose aggregates are present enough to cover large areas of the pavement surface and pavement surface texture is fairly rough. If parameters defined in moderate severity are extreme in nature, severe choice in severity is chosen. On the TA-SM-C-0001-001 link, the length and width of ravelling were 20.4 and 1.5 respectively. The severity was therefore slight as few pieces of aggregates were visibly dislodged and had 2.3% localized extent of occurrence.

4.2.1.6 Condition Analysis and Treatment Selection for link TA-SM-C-0001-001

These condition analysis and treatment selection processes were evaluated as the case for link TA-SM-C-0001-001 in Table 4.4 using the damage ratings in Table 4.5 with respect severity and extent of occurrence of defect of every road link as discussed for link TA-SM-0001-001 above to calculate the PCI for the road. Table 4.6 gives the correspondence of the PCI value in terms of some of the visual expectations on the road and the treatment alternatives to be provided per the PCI value of the road. As noted by Paterson, (1987) treatments recommended by this index based approach was helpful since most treatments can be seen to be correcting one or more defect groups. A seven point ranking is also provided to give even a layman in roads a fair idea of the condition of the road. In table 4.4, S1, S2 and S3 refers to Slight, Moderate and Severe in severity while E1, E2 and E3 represent localized, intermittent and prevalent in extent of occurrence.

With a PCI of 33%, TA-SM-C-0001-001 according to Table 4.6 the condition of TA-SM-C-0001-001 was a very poor road in ranking needing and overlay in 2-3 years with preceding repair work of carriageway and shoulders in the fully distressed areas. On the preceding repair works, the system made provision for thorough summary reports to be generated on every link within the network so the particular repair work needed could be known from the extent of occurrence and severity of peculiar defects.

Table 4.4: Pavement Condition Rating Form for link TA-SM-0001-001

Pavement distress Manifestation		Severity of Distress			Extent of Occurrence			Rating R	Weight W	Defect RxW
		Light S1	Moderate S2	Severe S3	E1 <15 %	E2 <16-30%	E3 >30 %			
Surface distress & Defects	Bleeding								2	
	Raveling/Stripping	S1			E1			1	1	1
	Aggregate loss								2	
	Longitudinal and transverse cracks								3	
	Meandering cracks								4	
	Potholes			S3	E1			4	4	16
	Peeling								3	
	Disintegration (Patching)		S2		E1			4	4	16
Deformation	Rutting without cracks								2	
	Shoving								4	
	Corrugation								2	
Structural distress	Alligator cracking								3	
	Depressions Settlements		S2			E2		4	4	16
	Rutting with cracks								4	
Edge & Shoulder	Shoulder deformation								2	
	Edge distress			S3		E2		5	3	15
ΣDEFECTS (RxW)										65
PAVEMENT CONDITION INDEX (I) = (20(5.00-1/20Σ(RxW))										35

Table 4.6 Pavement Condition Rating and Maintenance Activities Required

(the state of link TA-SM-0001-001 shown in red)

Pavement Condition Rating		Maintenance Activities Required	Ranking
Index	Visual Aspects		
91-100	Pavement is in excellent condition with no defect. Riding quality is excellent	No maintenance required	Excellent
81-90	Pavement is in good condition with very slight cracking and raveling. Riding quality is good	Only few recurrent maintenance required	Very Good
65-80	fairly good road condition frequent slight cracking and raveling, slight rutting and a few areas of slight alligator cracking, Riding quality is fairly good with intermittent rough and uneven section	Appropriate recurrent maintenance (local sealing and patching) required. Surface treatment in 3-5 years.	Good
51-64	Fair road condition with intermittent moderate and frequent slight cracking, ravelling and with intermittent moderate alligatoring and disintegration. Riding quality is fair and surface is slightly rough and uneven	Surface treatment within 2-3 years required with preceding extensive repair of carriageway (patching, leveling and reconstructing of distressed areas) and shoulders (filling).	Fair
41-50	Poor to fair road condition frequent moderate cracking, ravelling and rutting, intermittent severe alligatoring and disintegration. Riding quality is poor to fair and surface is moderately rough and uneven.	Overlay within 2-3 years required with preceding extensive repair of carriageway (patching, leveling, and reconstruction of distressed areas) and shoulders (filling).	Poor
21-40	Poor road condition frequent severe cracking, ravelling and potholing, intermittent severe alligatoring and disintegration. Riding quality is poor to fair and surface moderately rough and uneven.	Overlay within 2-3 years required with preceding extensive repair of carriageway and shoulders. Reconstruction of carriageway and shoulders in the fully distressed areas.	Very Poor
0.0-20	very poor condition extensive severe cracking, ravelling and rutting and alligatoring. Riding quality is very poor surface is very rough and uneven.	Reconstruction is indispensable	Failed

4.2.1.7 Prioritization

The link, TA-SM-C-0001-001, a paved road, had a priority ranking value of 585 obtained through priority evaluation; this was evaluated using an ADT value of 500, a PCI of 33% (table 4.4) and an economic factor of 5 as the link serves as a transport route to bring agricultural produce downtown.

$$\text{Priority Formula} = \frac{[(\text{Class Factor}) \times (\text{ADT Factor}) \times 1000]}{\text{Condition Factor}} + \text{Economic (Agricultural produce)}$$

Where Class Factor = 1.25 for Collector Roads (Class 'C')

ADT Factor = $(ADT/500)^{0.1} = (500/500)^{0.1} = 1$

Condition Factor = $10^{(PCI/100)} = 10^{(33/100)} = 2.137$

$$= \frac{1.25 \times 1.0 \times 1000}{2.137} + 5 = 585$$

4.2.1.8 NMT Lanes

Tamale is a town in Ghana that cyclist and footway use is very extensive, sometimes competing with motorist for road way use. Cyclists usually use the strip of road closest to the kerb. Problems frequently encountered by cyclists include pot holes, debris brushed to the side of the road and manholes which do not flush to the road surface. The standards dictate that there should not be more than a six millimetre vertical height difference between the carriageway and a manhole cover or drain but "the theory and the practice do not often match up on this". (HCTC, 2003). In addition, poor lighting and vegetation that was not trimmed back on off-road cycle paths and inadequate attention to cycle routes during road works were problems which this system which captures data on NMT lanes seeks to bring out. Swerving into the road to avoid potholes, flooded drains and encroached vegetation made use of NMT lanes unsafe. Maps of NMT lanes and NMT lane pavement types in Tamale developed by the system has been shown in Appendix F

4.3 System Interfaces

4.3.1 Base Information

The base information form (Figure 4.2) for this system presents the user with the basic information about a link, generation of links as well as defining new links. It also makes provision for the definition of the region, city and sub-metro in which the link is located.

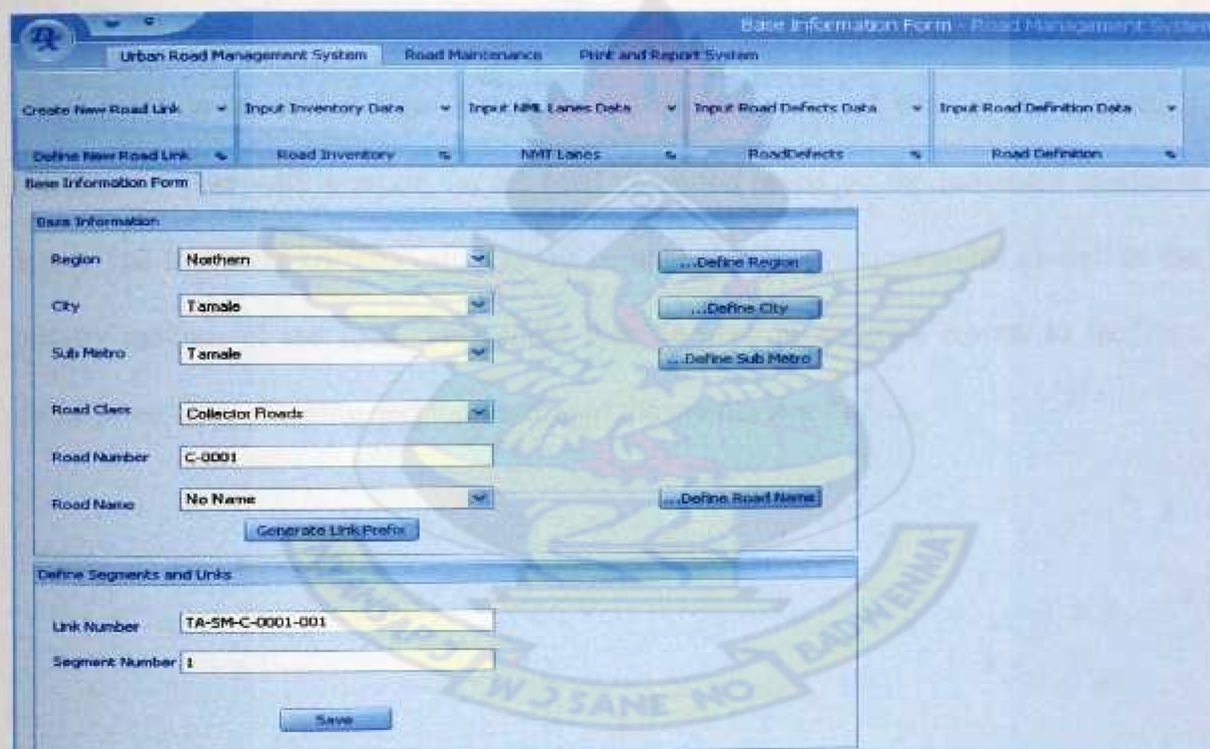

Figure 4.2 Base Information Form

4.3.2 Road Inventory and Condition

Figures 4.3 and 4.4 are the road defect and inventory forms respectively for the system which made provision for data input as well as search for links within the systems based on their peculiar definition, defect type or inventory. There are similar forms for the NMT lanes recordings. For the security of each of these entries into the system it is a prerequisite to click on the save button to save the entered information.

Also available is the applications forms which is used to start the data entry process. This requires that the region and city where the link is located is entered and saved. This helps the system to generate the sub-metro and a part of the road number and road link to reduce entry errors into the system. Double entries are also avoided as the system prompts the user and prevents this but gives an alternative for changes on a link to be made if the user has administrative privileges. The Road Maintenance Form unlike the other forms is an output form based on the decision support base of the system. It presents the user with a report on the road condition based on the pavement condition index. The treatment corresponding to the computed PCI is recommended as well as the priority ranking of the road. This could then be used to generate reports to facilitate decision making, planning and forecasting of the maintenance needs.

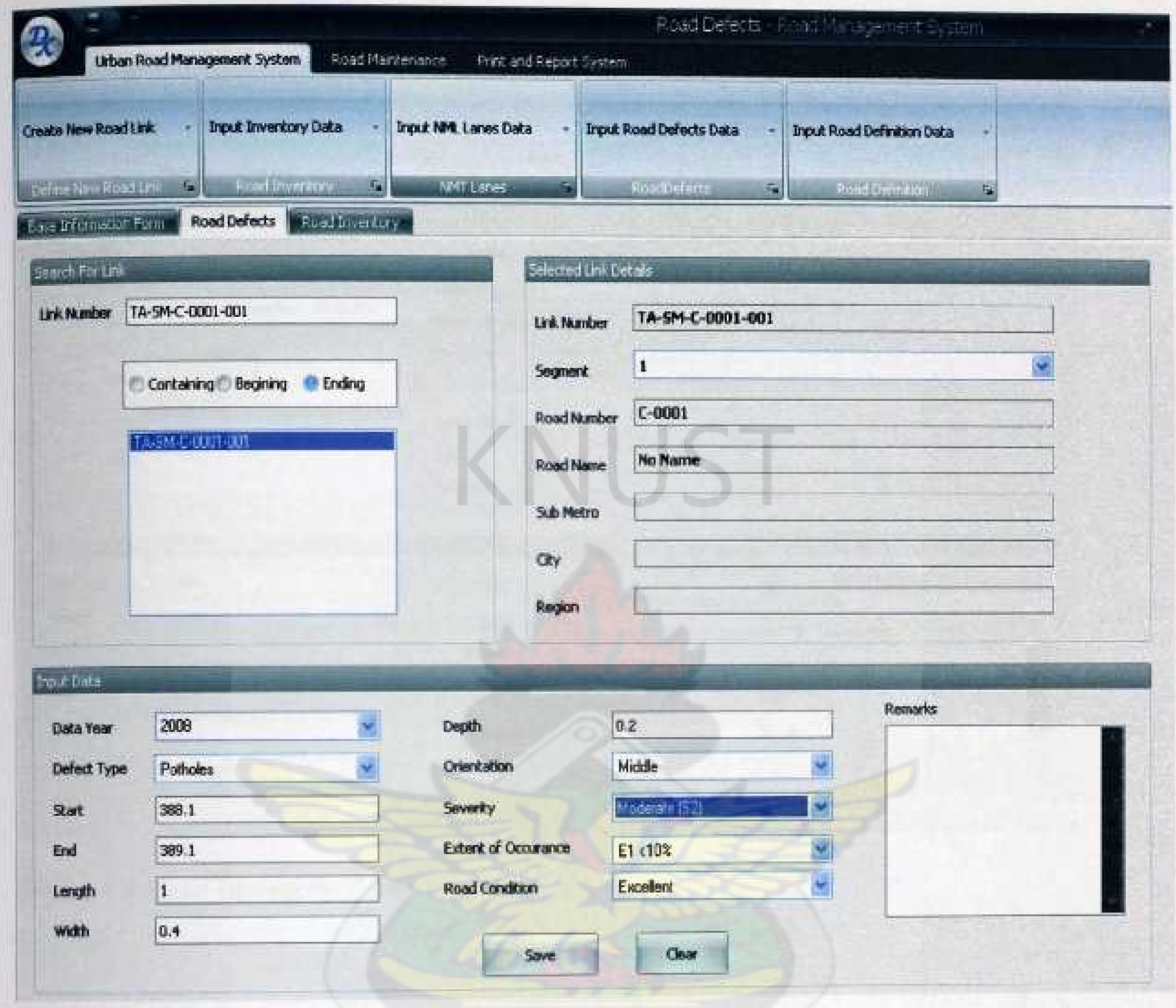

Figure 4.3 Road Defect Form

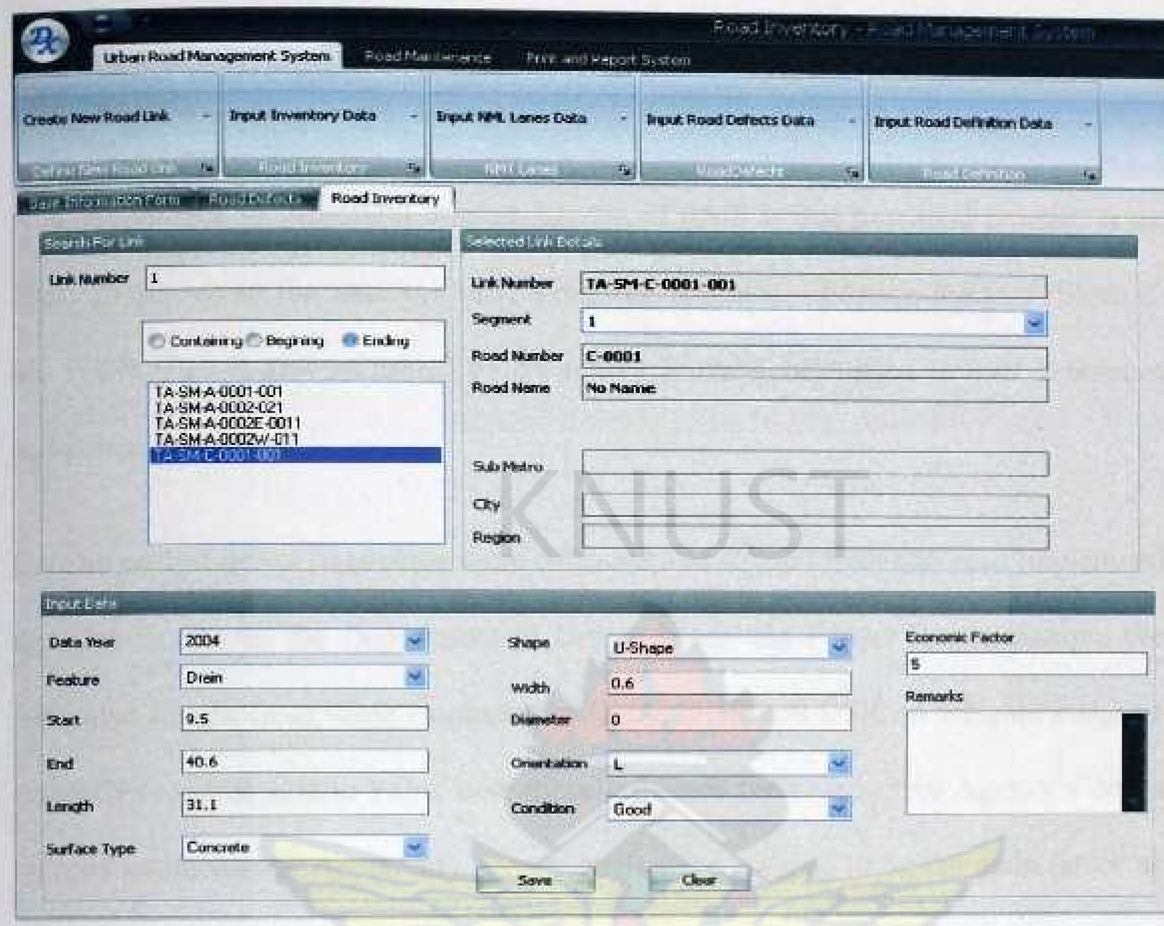

Figure 4.4 Road Inventory Form

4.3.3 Condition Analysis, Treatment Selection and Prioritization

A pavement management system developed for a western country may be inadequate for a country with very different traffic characteristics and administrative structure (Tillotson *et. al.*, 1998). This was confirmed in this study. While systems in western countries assigned higher priority to treatment of road defects at their inception (proactive approach) which in effect reduces road user cost as well as agency cost on maintenance and ensures a very good riding quality, the situation in Ghana is different. Due to insufficient budget allocation to road implementing agencies, a reactive approach to maintenance is often the case. The agency is coerced to assign part of its meager budget to maintain a road often as a result of public outcry. However, this give cause to high road user cost.

A major setback to successful implementation of RMS is that historical practice is more likely to determine the outcome than a realistic appraisal of future needs. (Tillotson *et. al.*, 1998). This is also worsened by dwindling financial allocation to road maintenance and public outcry.

Data on cost of defect treatments were collected and studied from two road implementing agencies in Ghana; the Department of Urban Roads and Feeder Roads. Sample views were also sought from some Engineers at GHA, DUR and DFR on weights assigned to respective road defects to know how these influence their respective Agency's decision on road maintenance. Apparently agency goals were realized to be the main factor as to which road was earmarked for maintenance but indirectly most of these had been due to the road users (public) outcry for maintenance due to poor riding comfort. These reflected in the weights assigned to defects (Table 4.4). In the analysis, structural defects had the highest potential to have serious consequence on pavement components and values assigned to them were also compared to the DRM system implemented by the Highway Preservation System in Ohio, USA whose condition analysis was also based on visual inspection as well as the use of PCI. It was realized that though the weights were different in value, the theory and logic behind them was comparable. Structural distresses had the highest weights, then edge and shoulder drop-offs and then surface distresses. But where the DRM, PMMP used at the GHA and the Road Asset Monitor uses a three point range of condition description, this system uses a seven point scale for better clarity.

The Good, Fair and Poor ranges can however be deduced from the seven point scale using their condition score values which in this system (URMS) is the pavement condition index (PCI).

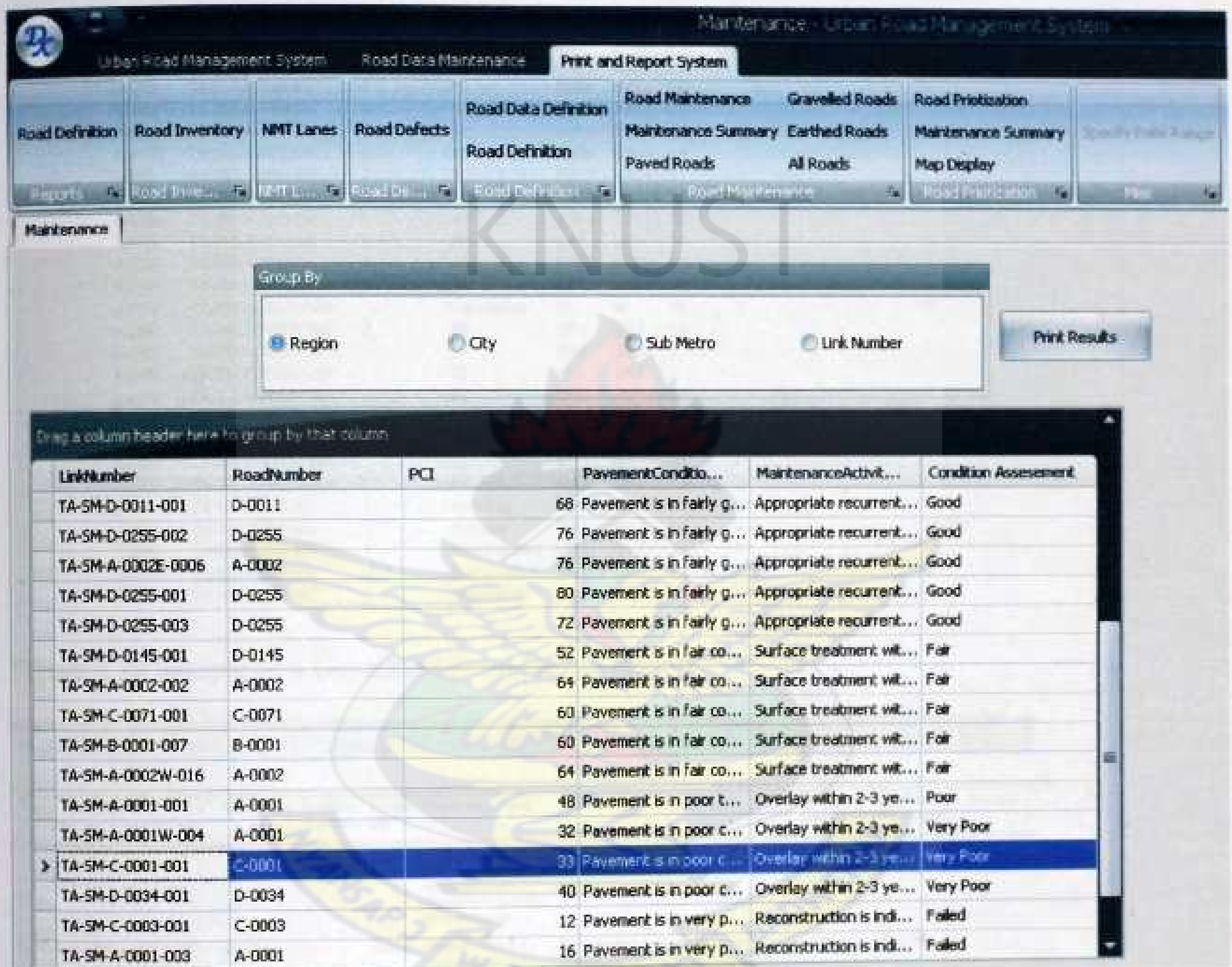

Figure 4.6 Output Form for Printing and Report Generation

4.3.4 Report Generation

While Figures 4.2, 4.3 and 4.4 are largely input forms, Figures 4.6, 4.7a and 4.7b are output forms which are generated based on the programmed expectations of the system. The road maintenance form, reports on the description of the road based on its PCI, recommends an appropriate treatment needed based on the categories of defects; surface distress and defects, deformation, structural distress and lastly shoulder and edge deformation (OECD, 1995) and presents a priority ranking of the urgency of the recommended maintenance.

Data Yr.	Road No.	Link Number	Seg. No.	Defect Type	Start	End	Width	Depth	Diameter	Orient
	A-0002	TA-SM-A-0002-029	1	AC	2211.2	2215.1	1.6			
	A-0002	TA-SM-A-0002-029	1	AC	2030	2034.7	0.4			
	A-0002	TA-SM-A-0002-029	1	AC	2003.7	2040.3	0.3			
	A-0002	TA-SM-A-0002-029	1	AC	2040.8	2084.2	0.6			
	A-0002	TA-SM-A-0002-029	1	AC	2140.9	2145.3	0.6			
	A-0002	TA-SM-A-0002-029	1	AC	2167.2	2195.7	0.7			
	A-0002	TA-SM-A-0002-029	1	AC	2293.6	2304.5	0.4			
	A-0002	TA-SM-A-0002-029	1	AC	1355.7	1362.4	1			
	A-0002	TA-SM-A-0002-029	1	AC	1797.9	1822.6	1.5			
	A-0002	TA-SM-A-0002-029	1	AC	2277.9	2279.5	0.7			
	A-0002	TA-SM-A-0002-029	1	EB	1394	1420	0.4			L
	A-0002	TA-SM-A-0002-029	1	AC	2166.2	2172.3	0.8			
	A-0002	TA-SM-A-0002-029	1	EB	1989.5	2000.7	0.5			L
	A-0002	TA-SM-A-0002E-0006		Corrugation	35	66	12	3		R
	A-0002	TA-SM-A-0002W-005	1	RU	197.1	217.9	0.6			
	A-0002	TA-SM-A-0002W-007		PO	290.7	291.7	2			
	A-0002	TA-SM-A-0002W-010		RT	69.4	147.8	1			
	A-0002	TA-SM-A-0002W-011		PA	12.9	13.9	2.4			
	A-0002	TA-SM-A-0002W-012	1	RU	99	148.1	1.2			
	A-0002	TA-SM-A-0002W-012	1	PA	148.5	149.5	4.5			
	A-0002	TA-SM-A-0002W-016		RU	209.5	269.3	0.8			
	A-0002	TA-SM-A-0002W-016		RU	125.5	185.2	1.3			
	C-0001	TA-SM-C-0001-001	1	Ravelling	52.6	73	1.5	0.1		R
	C-0001	TA-SM-C-0001-001	1	Potholes	388.1	389.1	0.4	0.2		Middle
	C-0001	TA-SM-C-0001-001	1	Disintegration	707.2	751.1	4	0		L
	C-0001	TA-SM-C-0001-001	1	Edge Distress	339.4	364.3	0.2	0.06		L
	C-0001	TA-SM-C-0001-001	1	Depressions	219.3	222.2	0.3	0.04		L

Figure 4.7a Sample of a Generated Road Defect Report

Road Number	Link Number	Road Name	Segment Number	Length (m)	Maintenance Needs	Visual Description	Priority Ranking	Condition Assessment	Remarks
					and shoulders Reconstruction of carriageway and shoulders in the fully distressed areas	quality is poor to fair and surface I moderately rough and uneven			
A-0001	TA-SM-A-0001W-004	No Name	1	1476.92	Overlay within 2-3 years required with preceding extensive repair of carriageway and shoulders Reconstruction of carriageway and shoulders in the fully distressed areas	Pavement is in poor condition with frequent severe cracking, ravelling and rutting, and with intermittent severe alligatoring and disintegration. Riding quality is poor to fair and surface I moderately rough and uneven	1003	Very Poor	
A-0002	TA-SM-A-0002W-003	Bolga Rd	1	137	Only few recurrent maintenance required	Pavement is in good condition with very slight cracking and ravelling. Riding quality is good	288.7142857	Very Good	
A-0002	TA-SM-A-0002-002	Bolga Rd	1	143.7	Surface treatment within 2-3 years required with preceding extensive repair of carriageway (patching, leveling and reconstructing of distressed areas) and shoulders (filling)	Pavement is in fair condition with intermittent moderate and frequent slight cracking, ravelling and with intermittent slight or moderate alligatoring and disintegration. Riding quality is fair and surface is slightly rough and uneven	303	Fair	
B-0001	TA-SM-B-0001-002	KUMASI ROAD	1	282.9	No maintenance required	Pavement is in excellent condition with no defect. Riding quality is excellent	171.666666	Excellent	

Figure 4.7b Sample of a Generated Road Maintenance Summary Report

Recommendations of treatment were based on categories because the treatment of a particular defect results in the treatment of another. The output form for printing and report generation presents input data reports on the base information on the road definition, road inventory, road defect and information on roads with NMT lanes. These reports can be printed, exported to and saved in MS Excel, PDF, rich text formats and can also be e-mailed. Appendix F shows more of these reports, some of which have been exported to MS Excel and used to plot graphs to graphically illustrate further analysis that can be performed.

This system partly reduces the problem presented by Prasada *et al*, (2006) "that one of the major constraints in preparing the road network management systems is the large volume of data needed for it". And, even if the data becomes available, the problem remains how to access and manage it. What the road agency now requires is the needed funds for the data collection and entry and this carried out over a period of time could be used in developing prediction and optimization models for road maintenance in the metropolis.

4.4 ArcGIS Thematic Map Generation

Global Information Systems (GIS), being a desktop geographic information system was used as the platform for the spatial database due to its varied advantages as discussed extensively in Section 2.11 of this report. The digital map, created in four layers represent an urban road network setting: Major Arterial roads, Minor Arterial roads, Collector roads, and Local roads (Figure 4.8) classified as Road classes "A", "B", "C" and "D" respectively. Some customized maps were generated (Figure 4.9).

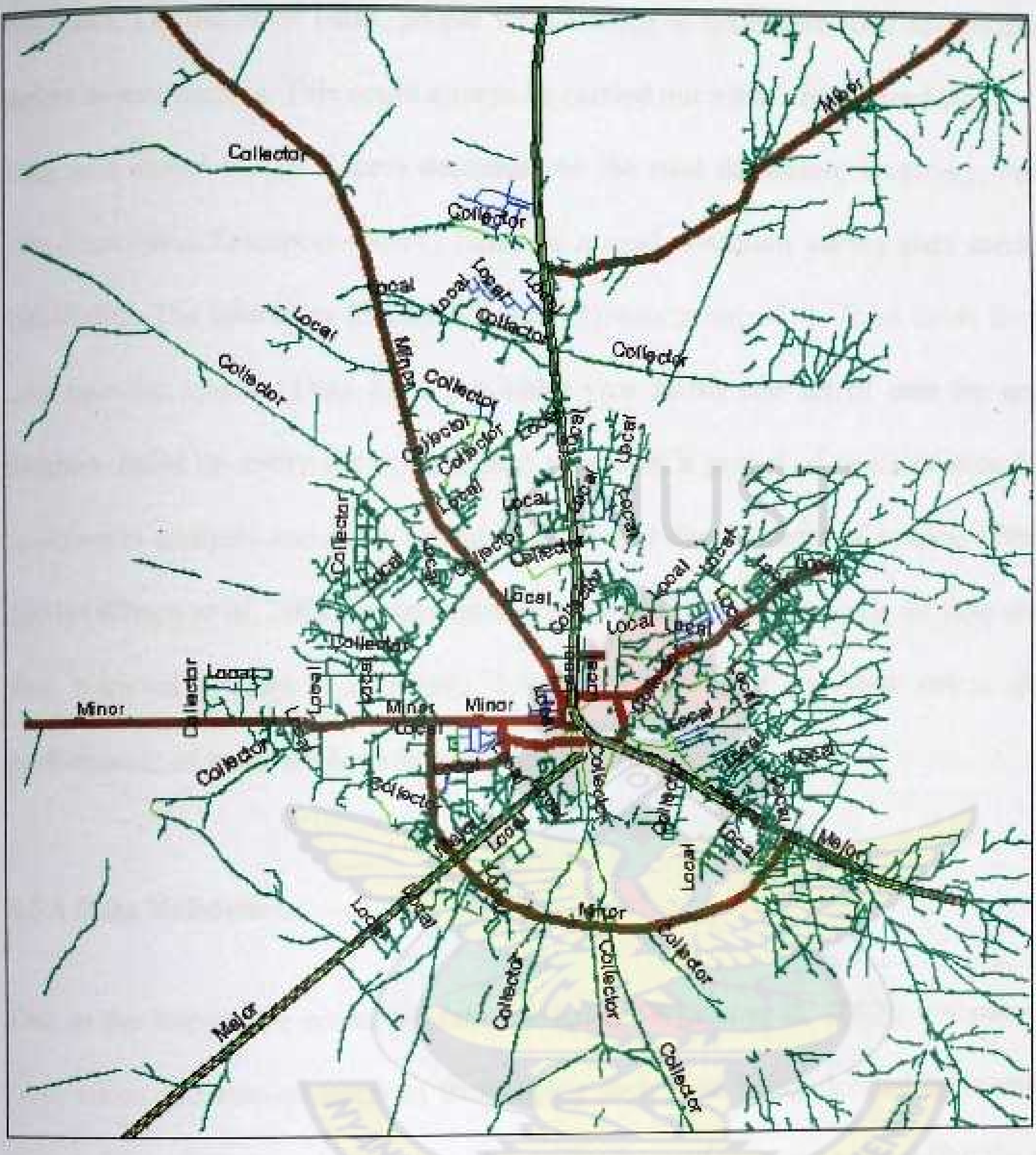

Figure 4.8 Tamale Road Network Classes

4.5 Data Management

On methods of defect assessment, manual measurement was preferred to Machine Based Method by the researcher as used in the Morogoro Roads support project (OECD, 1995). This selection was justified by inadequate funding for purchasing selected equipment and when even purchased, the inability of a developing nation like Ghana, to maintain such machines. On the other hand, people were trained to undertake road appurtenances and defect measurements. This could always be carried out when and as need be.

Data was stored in MS Access databases on the road definition, inventory, defects and Non-Motorable Transport (NMT) lanes of a road condition survey data carried out in 2004/2005. The interfaces (Figure 4.3 and 4.4) were some of the form fields for inputting data into the system. Data for a particular year forms one set of data for analysis. A database build up every (or every other) year over a period of years creates a basis for meaningful analysis and basis for formulation and development of models (Prasad *et al*. 2003) (Wilson *et al*, 2002) in road management systems. These fields for data storage and data retrieval (Figure 4.3, Figure 4.4) gives the right for data entry, query and performance of some analysis as permitted by the system.

4.5.1 Data Validation

Due to the imperative nature of data validation (Wilson et al, 2002), a number of steps were taken, paramount amongst them being each road being defined by a unique road link number to prevent duplication of record entry and ensure a unique link for data on a particular link. System calculations were also performed manually and compared with system computed results which gave consistent values and relevant outputs. As not all data traditionally collected was significant (Wilson et al, 2002), the data was well sorted to evade the effect of these on the output accuracy.

4.5.2 Data Analysis

The roads were classified into classes based on their functionality. Major Arterial, Minor Arterial, Collector and Local roads (Figure 4.8 and 4.9) which correspond to classes 'A', 'B', 'C' and 'D' respectively as used in the system. In all data a total length of 322.648 km on the Tamale road network were collected and entered into the system. Of these 154.018 km were paved and 168.486 km were unpaved roads representing 47.7% and 52.2% respectively of roads in the Tamale metropolis with link numbers. From the paved road length, 38.406 km, 31.594 km, 83.945 km were asphalt concrete, double surface dressed and single surface dressed representing 11.9%, 9.79% and 26.0% respectively of the total Tamale road network. 92.684 km were gravel roads and 75.805 were earth roads also representing 28.7% and 23.5% of the entire road network in Tamale as of 2005. The respective lengths of these road classes (Figure 4.10) indicate over 60% in category C and D. 70% of those in class D are unpaved, 50% are earthed roads and 20% are gravel roads (Appendix F). An indication that there were a lot of roads to be paved as the city grows. The roads were basically classified according to their functionality and these statistics (Figures 10 and 11) as well as Maps in Appendices D3, D4, and D5 confirms the researchers' assertion that the Capital City of the largest Region in Ghana with its rich agricultural, tourism and articraft resources is yet to experience massive developmental growth. On the other hand cost on road maintenance as of 200/2005 was expected to be rather low, compared with its counterpart cities with well developed (paved) road environments (Zietlow, 2000). With the consideration of tourist sites, agriculture producing areas, industries, educational institutions, security bases etc, in the prioritization the functionality of some of these roads can be said to have increased hence their need for upgrading and or urgent need for maintenance when there is minimal deterioration. Figure 4.11 reports the graphical pavement type distributions for the Tamale network.

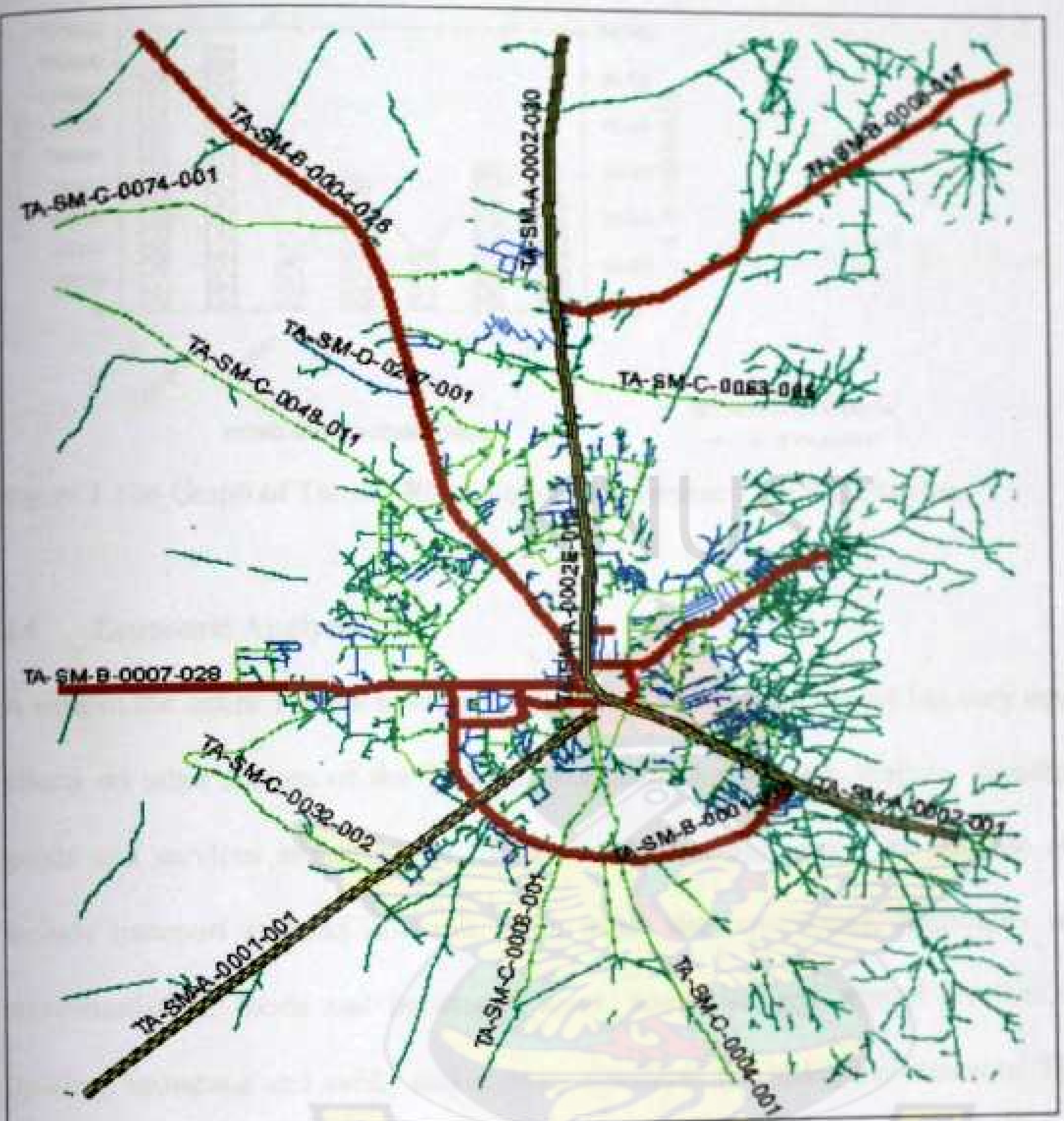

Figure 4.9 ArcGIS view of the Tamale Road Classes with roads without link numbers

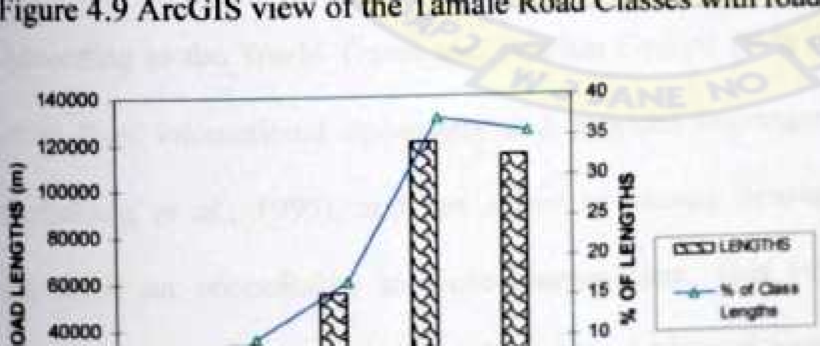

Figure 4.10a Graph of Tamale Road Network Class Distributions

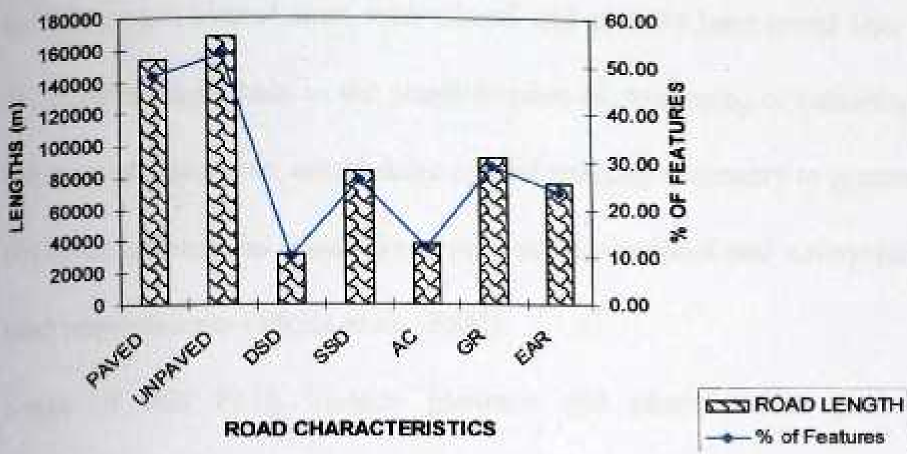

Figure 4.10b Graph of Tamale Road Network Pavement Type Distributions

4.6 Economic Analysis

A view of the entire Tamale road network and its proper management has very significant effects on other sectors of the Tamale metropolis. Agriculture, tourism, distribution of goods and services are a few of these. For the tourism sector, its tangible elements include transport systems -air, rail, road, water and now, space; hospitality services-accommodation, foods and beverages, tours, souvenirs; and related services such as banking, insurance and safety and security constitute the intangible elements. These are all accessed by road in Tamale.

According to the World Travel and Tourism Council (WWTC) tourism develops twice more than international economics and provides important employment possibilities (Lundberg *et al.*, 1995), and has a part in country development but this is heavily depended on accessibility to these tourism sites. This validates the thematic maps generated by this system. This easily creates a pictorial awareness of road surface and pavement type to a particular location and protective mechanisms to put in place if need be. For as the surface classes of roads have been shown, so could information including natural, recreational, and historic tourism entities, transportation facilities, tourism facilities, agricultural sites, educational and security base could also be similarly shown. These advantages help in the simplification of processing of voluminous geographic-road information, and also, could drive spatial analyses necessary to generate thematic maps or statistical reports, as much for academic, institutional and enterprise interest as for own road requirements (Mejia et al., 2002).

Users of this PMS include planners and administrative personnel, organizations, politicians, educational institutions, public, industry/companies. (Garagon, *et al* 2002) and road maintenance engineers. With road transport being the principal transport facility in Ghana responsible for 97% and 94% of all national passenger and freight traffic respectively, analysis and data from systems such as this will continuously play a primary role in the socio-economic growth in the medium and long term. (GHA-HNMP, 2000) and will facilitate policy formulation and passage into law to enforce use of PM.

4.7 Testing and Packaging of the system

The system was installed and run on a number of computers to ensure a smooth operation and reports generated were printed. Some problems were encountered during the testing stages. These were however resolved with the installation of Development Express, an application software which was used to enhance the graphical user interface of the system. This therefore needs to be installed before running the program. Also to view maps generated by the system, ArcReader has been added for installation to assess the maps. Reports were also exported to MS excel and used for further analysis. The software was written unto a compact disc which could be accessible to all when due permission is acquired to use it from the Department of Civil Engineering, KNUST.

Chapter V

CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusions

This study has developed an urban road maintenance management system using the pavement condition index based method which is a condition responsive treatment selection type and the Tamale network data in Ghana.

This system brings under one umbrella a pavement management system, a road inventory information system, an NMT lane information system and an ArcGIS pavement, road inventory and NMT lane map generation system. The system offers answers to the Tamale road network in particular and can also be adapted to road networks which have no NMT provision.

Provision has been made for upgrade of the system with newer data as well as new road links. Its database format makes it capable of exportation of output to other systems like the MS Excel, HDM-4, Text Document etc. for further analysis.

Customized maps in GIS environment and reports on data input, treatment recommendations and priority rankings of roads on their urgency of treatment were generated.

5.2 Recommendations

The research can only be said to be one of the foundations for further advanced research into this area of study in Ghana such as:

- Building a base model for prediction of future road condition using analysis on historic road conditions data

- Incorporation of regression analysis and optimization models in Road Management Systems (RMS) in Ghana.
- Development of an Integrated Asset Management System for Ghana which incorporates Agricultural product producing areas, tourist sites, company locations, major hospitals, military routes etc. which will all be factored into prioritizing of roads and creating a facility for immediate response to emergencies.

It is recommended that this system sees further fine tuning and upgrades to metamorphose into an always abreast with time road maintenance management system.

Due to recent developments in Tamale new links have been created. These were discovered during the road condition survey and will need to be classified and given link numbers for incorporation into the system. Data collected on these must be used to update this system. Data ought to be collected on continuing bases to update the system.

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APPENDICES

APPENDIX A1

Questionnaire on Pavement Defect Perception – User /Agency Perspective

Please assign weights to these Defects: **1, 2, 3 or 4**

The questionnaire is to get your perception of the damaging effects of different defects, their consequence road user cost, cost of rehabilitation and the level of riding discomfort these cause to road users. Weights were expected to be assigned to these defects based on these factors. A weight range of 1, 2, 3 or 4 are expected to be assigned to these defects. Weight 4 warrants the most urgent treatment, the incurring of most cost of rehabilitation, highest road user cost or causing the most discomfort to road users making the road worst in safety to motorists. Weight 1 warrants comparatively the least of the factors outlined for weight 4. Ignore non-applicable defect

Pavement distress Manifestation		Weight (W)
Surface distress & Defects	Bleeding	
	Raveling/Stripping	
	Aggregate loss	
	Longitudinal and transverse cracks	
	Meandering cracks	
	Potholes	
	Peeling	
	Disintegration	
Deformation	Rutting without cracks	
	Shoving	
	Corrugation	
Structural distress	Alligator cracking	
	Depressions Settlements	
	Rutting with cracks	
Edge & Shoulder	Shoulder deformation	
	Edge distress	

APPENDIX A2
Guidelines for Paved Road Defect Measurement
(Source: GHA-MOM, 2001)

Distress Type	Description	Severity	Extent of Occurrence
Alligator Craking	Interconnected cracks caused by fatigue due to repeated loads	**L**: fine parallel longitudinal cracks. Mostly less than 6mm wide **M**: Network cracks with some spalls often less than 12mm wide. **S**: Well defined pieces that may rock under traffic and spalled at the edges and generally more than 12mm wide.	**L**: 1-15% of section affected **M**: 16-30% of section affected **H**: >30% of section length affected
Depression / Sags	Localized pavement surface areas with elevations less than the normal.	**L**: <20mm deep **M**: 20mm – 50mm deep **S**: >50mm deep.	=do=
Rutting	Longitudinal depressions in the pavement surface that occur in wheel paths of the roadway	**L**: <10mm deep **M**: 10mm – 25mm deep **S**: >25mm deep.	=do=
Bleeding	A shiny, glass- excessive amounts of asphalt cement in mix and/ or low air void content	**L**: asphaltic noticeable in pavement wheelpath but not covering the aggregate **M**: asphalt covering large portions of pavement surface **S**: >asphalt is totally covering the aggregates	=do=
Ravelling	weathering of the pavement	**L**: few pieces of dislodged aggregates siting on	

/ Stripping / Fretting	surface away	pavement surface **M**: pieces of loose aggregate present enough to cover large areas the pavement surface **S:** loose aggregate so prevalent causing very rough surface texture, severely pitted and discomfort when driving	=do=
Transverse Cracking	Cracks running perpendicular to the direction of traffic flow.	**L**: <6mm crack width and no or minor spalling **M**: 6mm – 12mm crack width, moderate spalling **S:** 12mm crack width, high severity spalling.	**L**: ave. crack spacing >70m **M**: ave. crack spacing btn. 30-70m **H:** ave. crack spacing <30m
Longitudinal / Edge Cracking	These occur parallel to the direction of traffic flow.	**L**: <6mm crack width and no or minor spalling **M**: 6mm – 12mm crack width, moderate spalling **S:** 12mm crack width, high severity spalling.	**L**: 1-15% of section affected **M**: 16-30% of section affected **H:** >30% of section length affected
Lane / Shoulder drop off	The difference in elevation between the pavement edge and the shoulder.	**L**: 25 to 50mm elevation difference **M**: 50 to 100mm elevation difference **S:** Elevation difference more than 100mm.	=do=
Patching	An area of pavement replaced with newer material to repair a pavement distress or utility cut.	**L**: patch shows no sign of deterioration and little effect on ride quality **M**: slight effect on ride quality and patch is somewhat deteriorated. **H:** rough, showing signs of disintegration and failure	=do=

Potholes	Less than 1m diameter sharp edge and vertical sided bowl-shaped depressions on the pavement surface.	**Pothole Level** 1 .existing potholes have a total area less than $10m^2/km$ **2.** Existing potholes have a total area of more than $10m^2/km$ but less than $30m^2/km$ **3.** Existing potholes have a total area of more than $30m^2/km$ but less than $50m^2$ **4.** Existing potholes have a total area of more than $50m^2/km$. NOTE: For each all the conditions above, estimate the area of potholes and add them for a representative 1km	
Excessive Height	Shoulder elevated over road surface	**L**: <50mm difference in height **M**: 50-100mm difference in height **S**: >100mm difference in height	L:1-20% of roadway length affected M: 20-50% of roadway length affected S: >50% roadway length affected
Overgrowth	Shoulder and roadway edge encroached by vegetation	**L**: growth begins to creep past the shoulder rounding line with a height less than 0.3m **M**: growth past shoulder rounding line onto main shoulder area with height between 0.3 and 0.6m **S**: growth over entire shoulder or even onto travelway edge with height >0.6m	**=do=**

APPENDIX A3

Guideline for Gravel Roads Defect Measurement (Source: GHA-MOM, 2001)

Type of Distress	Description	Severity	Extent Measured
Gravel Thickness (loose gravel)	Depth of compacted gravel	Loose aggregates on the road surface L: wind-rows <50mm gravel thickness M: multiple wind-rows 50-200mm thick S: multiple wind-rows >200mm thick	L: 1-20% of roadway length M: 20-50% of roadway length S: >50% of the roadway length
Dust	Traffic action creating dust cloud and aggregate segregation.	L: thin dust cloud M: Dust cloud which reduces visibility S: Dust cloud which reduces visibility almost completely.	=do=
Corrugations	A series of closely-spaced crests and valleys. Its ripples are perpendicular to the direction of traffic.	L: height of ripple <25mm M: height of ripple 25-50mm S: height of ripple >50mm	=do=
Rutting	Longitudinal depression in the road surface that occur in the wheel paths of a roadway	L: 60-120mm depression M: 130-200mm depression S: >200mm depression	=do=
Depression	Noticeable dips or bumps noticeable on giving rise pitch or drop in a moving vehicle	L: barely noticeable pitch or drop M: Noticeable pitch and harsh drop S: Continuous pitch and harsh drop of vehicle while in motion	=do=
Erosion Gullies	Longitudinal depression in road surface along wheel paths and sides of roadway often caused by running water.	L: <100mm depression M: 100-200mm depression S: >200mm depression	=do=
Vegetation Encroachment		L: only grass encroachment onto roadway or ditch M: grass and shrub encroachment S: grass, shrub and trees encroachment	=do=
Flat or Reverse Crown	No or flat camber or road edges higher than edges	Always extreme	=do=

APPENDIX A4.

Examples of Flexible Pavement Distress Definitions (According to Hass 94)

Types of Distresses	Description	Severity Levels	Extent Measures
Alligator cracking	Interconnected cracks caused by fatigue due to repeated loads	L: Fine parallel longitudinal cracks M: Network of cracks with some spalls H: Well- defined pieces that may rock under traffic and spalled at the edges	Square feet of surface area
Block cracking	Interconnected cracks caused by shrinkage of the asphalt and daily temperature cycling. Size of block ranges from 1 to 10 feet. Generally occurs over a wide area of the pavement surface.	L: Any filled crack or nonfilled cracks less than 3/8 inches. M: Nonfilled cracks 3/8 to 3 inches. wide or nonfilled cracks up to 3 inches wide surrounded by light random cracking H: Any crack surrounded by random cracking or nonfilled crack more than 3 inches.	Square feet of surface area
Distortions	Corrugations, bumps, sags, and shoving. Abrupt upward or downward displacements of the pavement surface. Distortions are evaluated relative to the effect on ride quality.	L: Cause vibration in the vehicle but do not require the vehicle to be slowed M: Significant vibration in the vehicle, some reduction in speed is necessary for safety and comfort H: Excessive vehicle vibration requires considerable speed reduction for safety and comfort	Square feet of surface area

Longitudinal and transverse cracking	Cracks that are either parallel or transverse to the pavement centerline. Longitudinal cracks are generally related to construction or defects and transverse cracks are related to temperature variations and hardening of the asphalt.	L: Any filled crack or nonfilled cracks less than 3/8 inches. M: Nonfilled cracks 3/8 to 3 inches wide or nonfilled cracks up to 3 inches wide surrounded by light random cracking H: Any crack surrounded by random cracking or nonfilled crack more than 3 inches.	Square feet of surface area
Patching and utility cuts	Repair of the pavement with new material.	L: Patch in good condition and does not affect ride quality M: Moderate deterioration, some effect on ride quality H: Severe deterioration, with high severity effect on ride quality	Area of patching
Rutting	Depression in the transverse profile of the pavement surface.	L: Less than 1 inch depth M: 1 to 2 inch depth H: More than 2 in depth	Square feet of surface area

APPENDIX A5.

Examples Of Aggregate Road Surface Distress Types (According to Hass 1994)

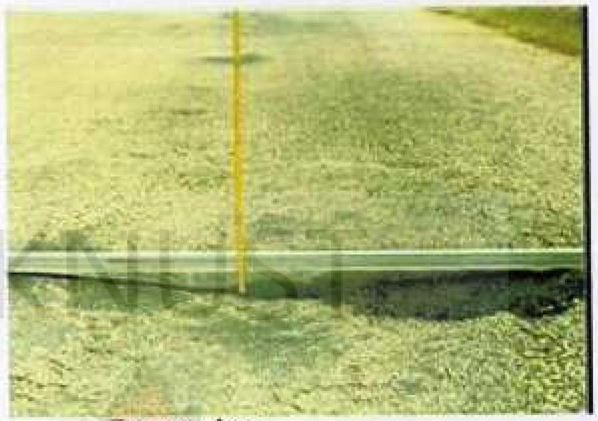
Types of Distresses	Description	Severity Levels	Extent Measures
Improper cross section	Not enough crown for proper drainage.	L: Small amounts of ponding water M: Moderate amounts of ponding water H: Large amounts of ponding water, road surface contains severe depressions	Measure linear feet along the center line of the affected area
Inadequate drainage	Evaluate ability of ditches and culverts to carry away water.	L: Small amounts of water ponding and/or overgrowth and debris in ditches M: Moderate amounts of ponding in the ditches or overgrowth and debris and erosion of the ditches into the shoulders and the roadway	Linear feet of affected area measured along the center line
Corrugations	Closely spaced ridges and valleys at fairly regular intervals.	L: Corrugations are less than 1 inch deep M: Corrugations 1 to 3 inches deep H: Corrugations more than 3 inches deep	Square feet of affected area
Potholes	Bowl-shaped depressions in the road surface usually less than 3 feet in diameter.	L: Less than 2 feet in diameter and less than 2 inches deep or less than 1 feet in diameter and 2 to 4 inches deep M: More than 4 inches deep and less than 1 feet in diameter, or 2 to 4 inches deep and 1 to 2 feet in diameter, or more than 2 feet in diameter H: More than 2 inches deep and more than 4 feet in diameter	Count the number of each severity level in the sample area
Ruts	Depressions in the wheel path.	L: Less than 1 inch deep M: 1 to 3 inches deep H: More than 3 inches deep	Square feet of affected area
Loose aggregate	Aggregate particles are separated.	L: Loose aggregate on the road surface M: Moderate aggregate berm on the shoulder or less traveled area; a large amount of fine area on the road surface H: Large aggregate berm on the shoulder and less traveled area	Linear feet parallel to the road surface

APPENDIX A7

Defect Catalogue for Defects in Bituminous Surfaced Pavements

(Source: MOM, GHA, GTZ, 2003)

Alligator Cracking



Depression

Bleeding

Rutting

shoulder distress: **overgrowth**

shoulder distress: **ponding**

ravelling

transverse cracking

edge breaking

lane/shoulder drop off

patching

potholes

APPENDIX A8

Defect Catalogue for Gravel Roads

(Source: MOM, GHA, GTZ, 2003)

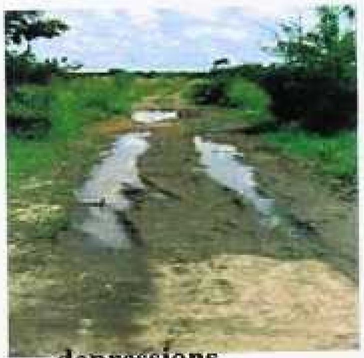
flat or reverse crown

soft spot

vegetation encroachment

slippery/rocky surface

erosion gullies



depressions

loose gravel **rutting**

potholes **corrugations**

APPENDIX B

DEFINITIONS

- ***Decision-support systems*** comprise applications modules to process the data and provide the information on which decisions can be based and, ultimately, implemented.
- **Attribute database** contains the non-geographical data, such as segment names and facility age describing a geographical feature.
- **Geographical database**, contains data that define the physical location of features, such as a segment of road.
- ***Geodatabase*:** An ArcGIS geodatabase is a collection of geographic datasets of various types held in a common file system folder, a Microsoft Access database, or a multiuser relational database (such as Oracle, Microsoft SQL Server, or IBM DB2).
- **Geo-relational data structure** links the location and attributes data. The link will establish the relationship between the location of features in the geographical database and their corresponding descriptions in the attribute database
- ***Information system:*** collects, organises and stores data
- ***Item inventory:*** relates to physical attributes of the road. These remain physically constant over time such as lengths and widths of carriageways and footways, drainage, road signs and the like.
- ***Level of Service (LOS)*** = A customer-oriented term that describes the condition of certain features of the highway system.
- ***Link***: a length of road that is uniform in terms of traffic volume it carries

- ***Maintenance Management:*** Used for planning organizing, directing and controlling a System maintenance operation,.
- ***Network*****:** all paved and unpaved roads providing ground access.
- ***Network information**:* An information system, as defined above, containing data about the highway network.
- ***Operations:*** Decision-support system for the management of operations on a daily or weekly basis, including defining work to be carried out, developing appropriate costs for this in terms of labour, equipment and materials, and making arrangements for carrying out the work by force account or by contract, the recording of work accomplishment, and the use of this information for monitoring and control.
- ***Pavement Condition Index (PCI)*** is defined as an index reflecting the composite effects of varying distress types, severity level, and extent upon the overall condition of pavement.
- ***Planning**:* Decision-support system for strategic planning undertaken to develop long term plans for the highway network as a whole; planning time horizons typically of five years or more; undertaken to determine what are the implications resulting from meeting objectives in terms of future budget needs, consequential pavement conditions, user costs, *etc*.
- ***Preparation**:* Decision-support system for project preparation, including project formation and design, costing, works order or contract preparation and issue.
- ***Programming**:* Decision-support system for tactical planning or programming concerned with determining need in the budget year; planning time horizons of one to three years; including identification of links or sections from the network which require

treatment and the timing of treatments, possibly in conjunction with a rolling programme; cost estimating, prioritisation, budgeting, monitoring.

- ***Performance-Based Budget***: An annual maintenance budget that is derived from application of a maintenance management system, based on specific amounts of work planned for specific maintenance activities, using inventory values, quantity standards, activity planning values, and unit costs,
- ***Project***: a section of roadway having similar age, geometry, and construction type.
- ***Route***: a length of road between an origin and a destination
- ***Sample unit***: a subdivision of a segment allowing detailed analysis and recording of facility defects. It is commonly, though not always, a 100-foot portion of a segment.
- ***Section***: a length of road that is uniform in terms of its physical characteristics
- ***Segment***: a subdivision of a project, a length of road that is uniform in terms of its geometric characteristics. There may be one or more segments within a project, such as city blocks.

Urban Road Maintenance Management System for the Tamale Metropolis

APPENDIX C

FIELD DATA COLLECTION FORM

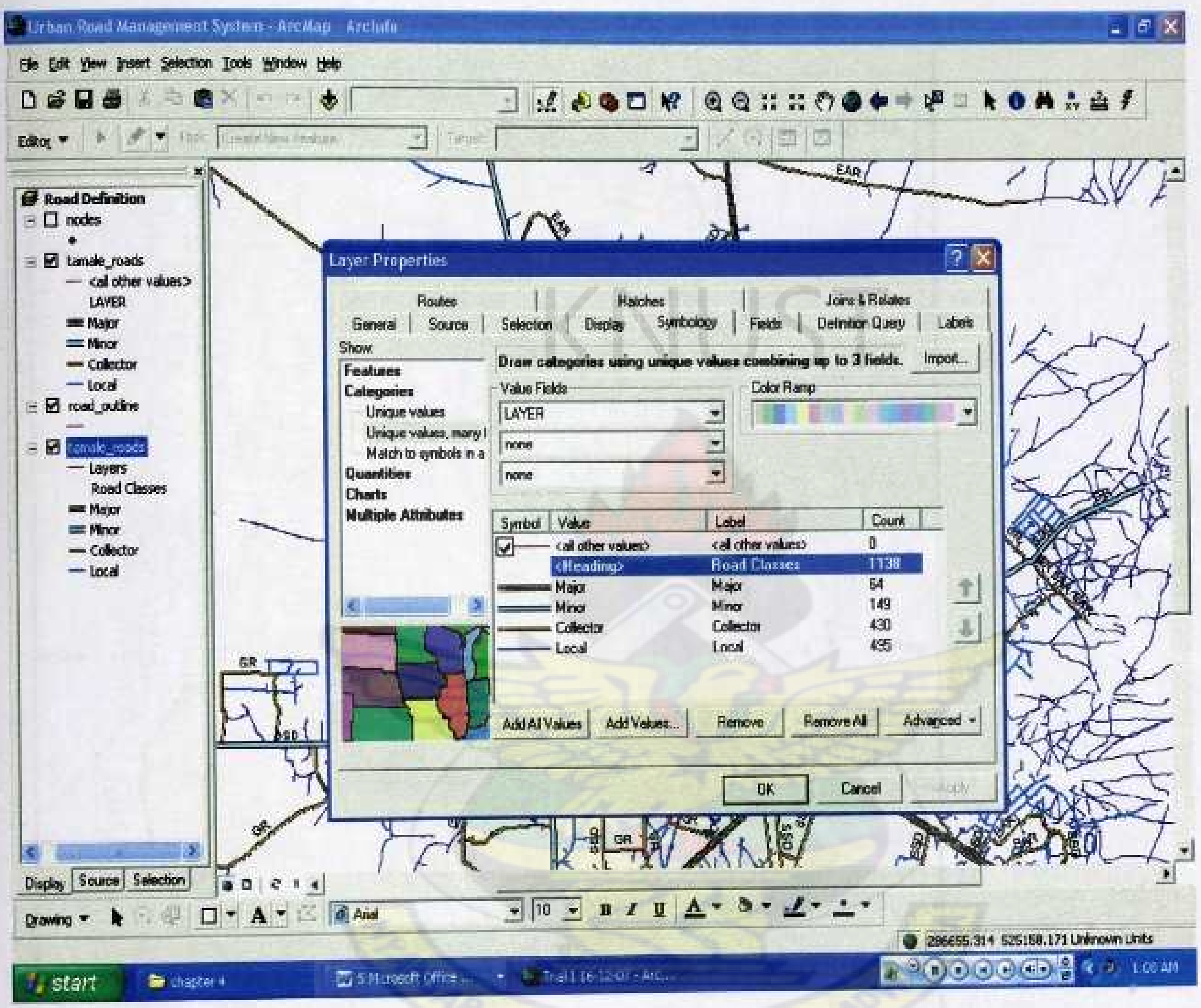
ROAD CONDITION SURVEY FORM (PAVED)

Road Nam Segment No:………… | Pavement Type | Day / Month / Year | DEPARTMENT OF URBAN ROADS
Link No.: ..Carriageway Width: ……… | AC ( ) | ………/……/……. | MUNICIPAL ROADS DEPARTMENT
Start Node No. of Lanes: 2 ( ) | SSD ( ) | | RCSP 1
End Node: ...3 ( ) | DSS ( )
4 ( )

RUTTING				POTHOLES			PATCHING			EDGE STEP				EDGE BREAK				ALLIGATOR CRACKING			LONG CRAKING			TRANSVERSE CRACKING			CORRUGATION			DEPRESSION			SHOVING			BLEEDING			RAVELLING		
START	END	WIDTH	DEPTH	START	END	WIDTH	START	END	WIDTH	START	END	WIDTH	DEPTH	START	END	WIDTH	DEPTH	START	END	WIDTH	START	END	WIDTH	START	END	WIDTH	START	END	WIDTH	START	END	WIDTH	START	END	WIDTH	START	END	WIDTH	START	END	WIDTH

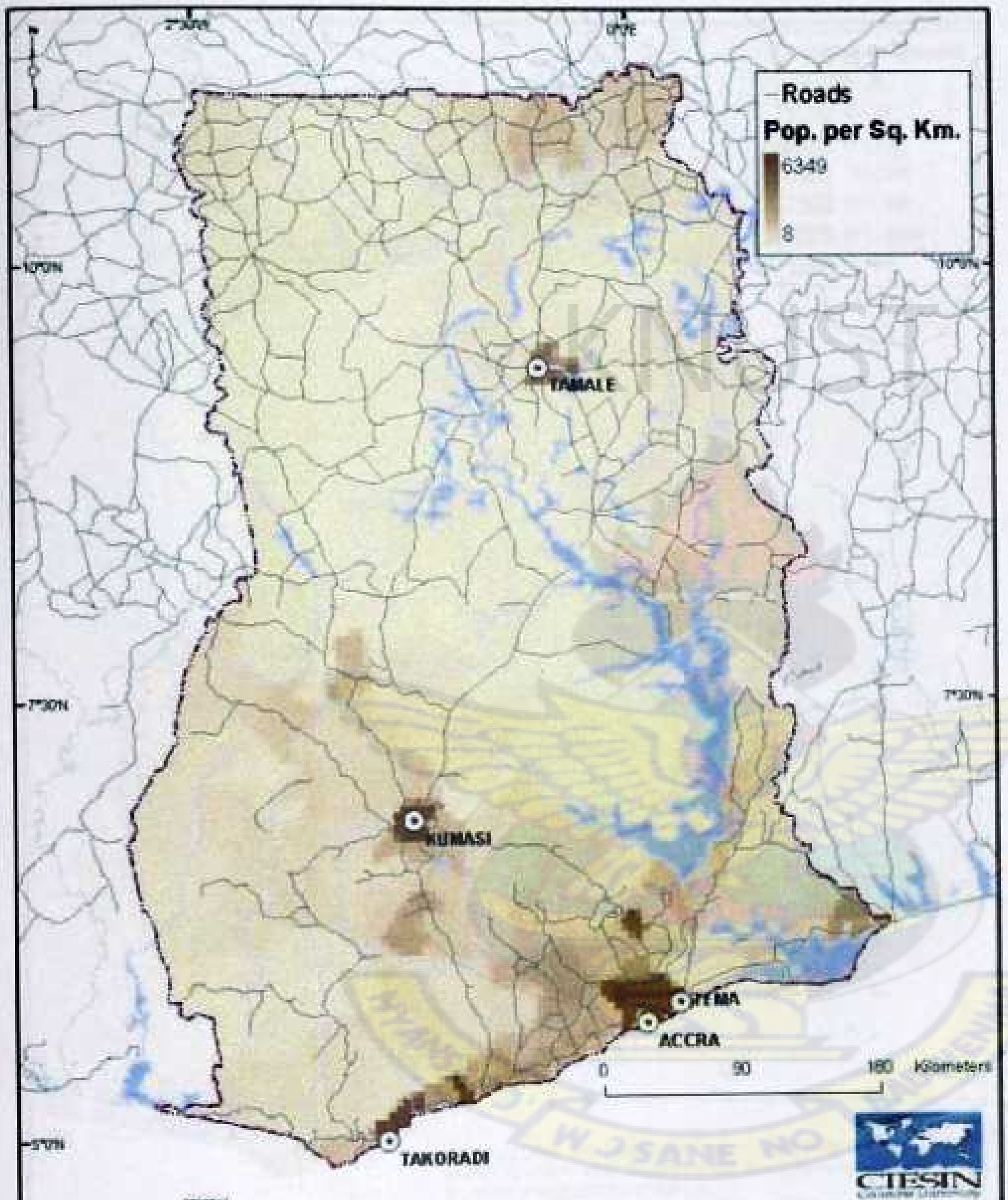
APPENDIX D MAPS

Appendix D1: ArcGIS summary view of the Number of each Tamale Road Class



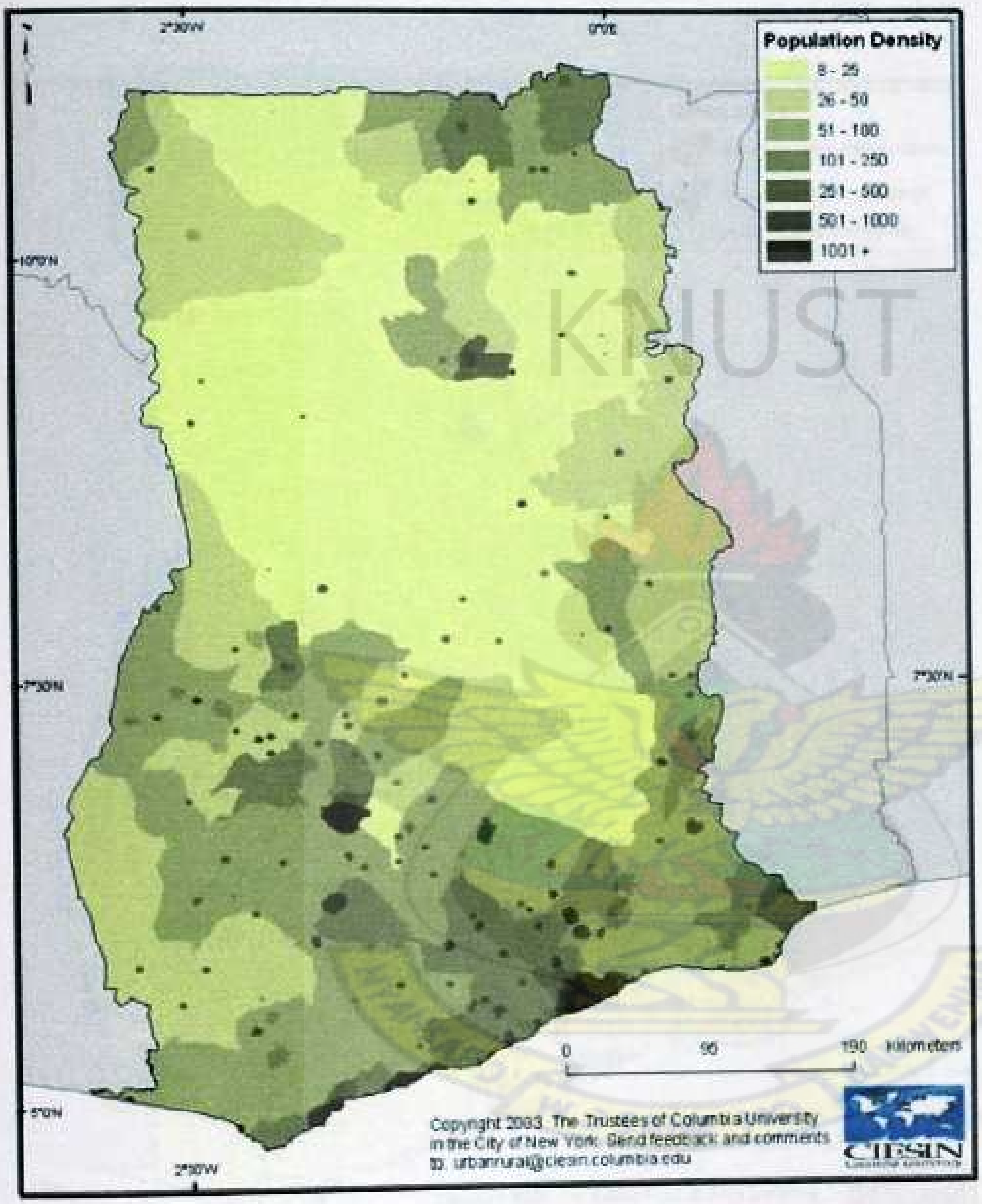
Appendix D2: Ghana Roads with Population Density

Source: http://www.ghanaweb.biz/GHP/img/pics



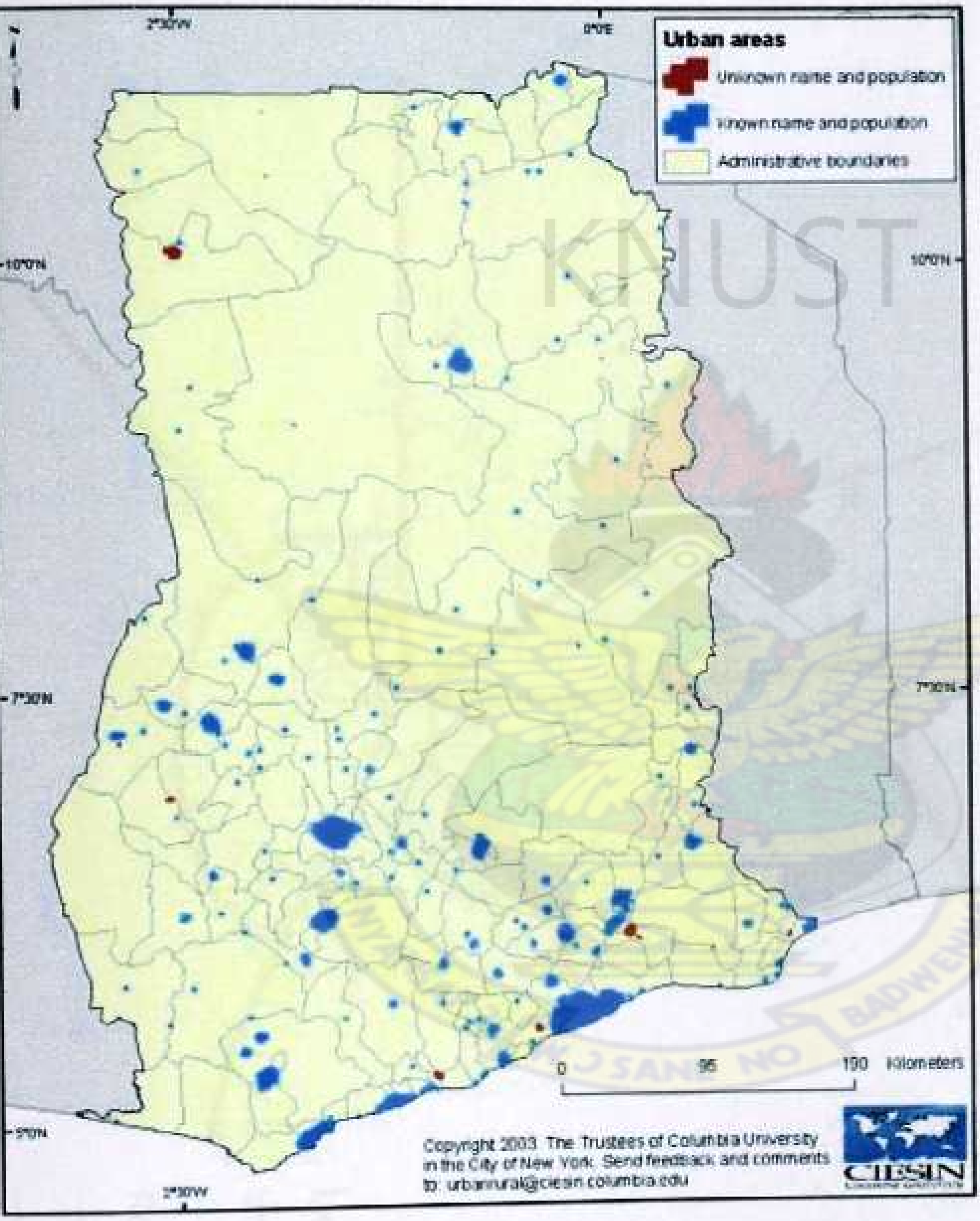
Appendix D3: Ghana Population Density

Source: http://www.ghanaweb.biz/GHP/img/pics

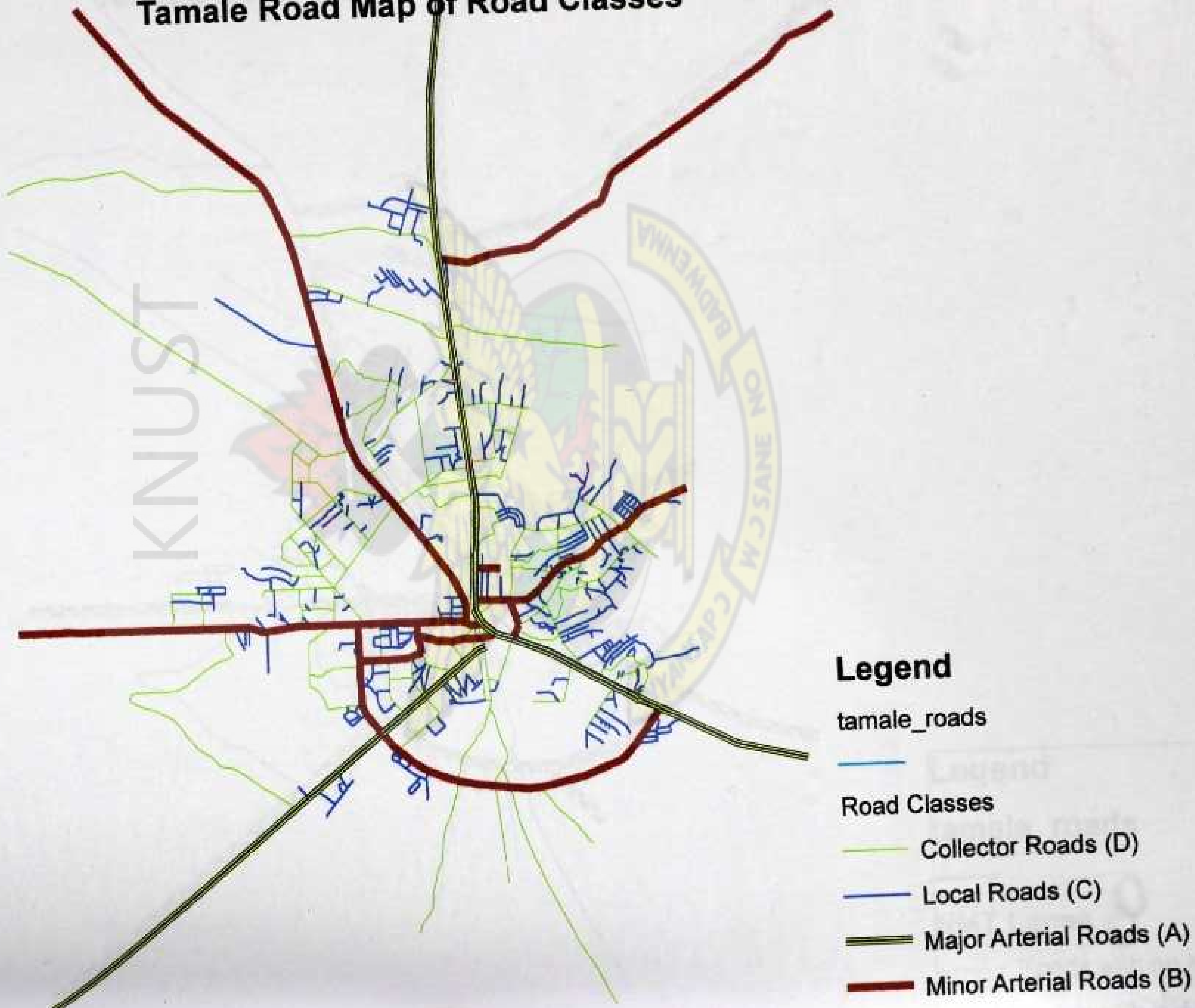


Appendix D4: Urban Areas in Ghana

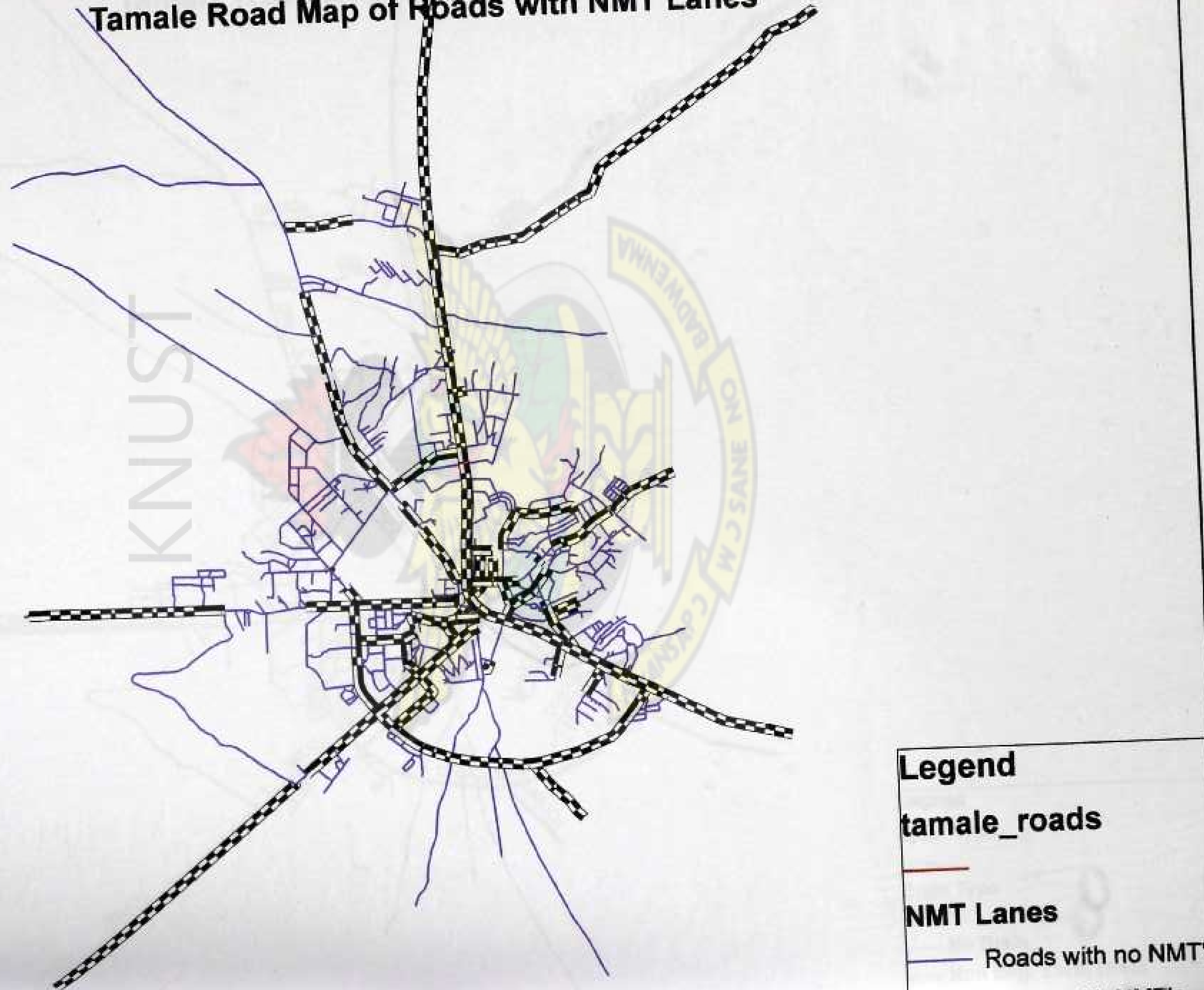
Source: http://www.ghanaweb.biz/GHP/img/pics



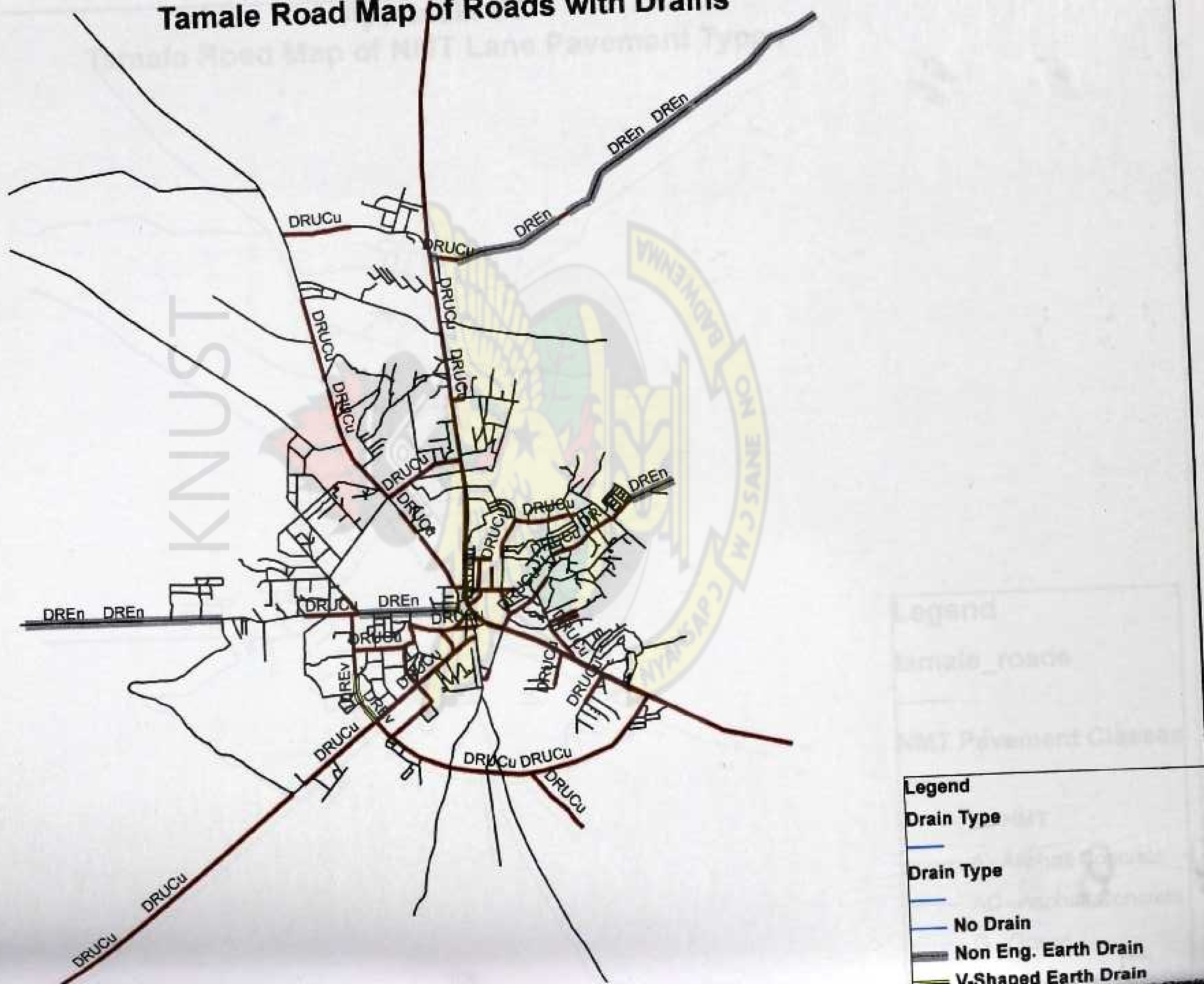
Appendix D5:
Tamale Road Map of Road Classes



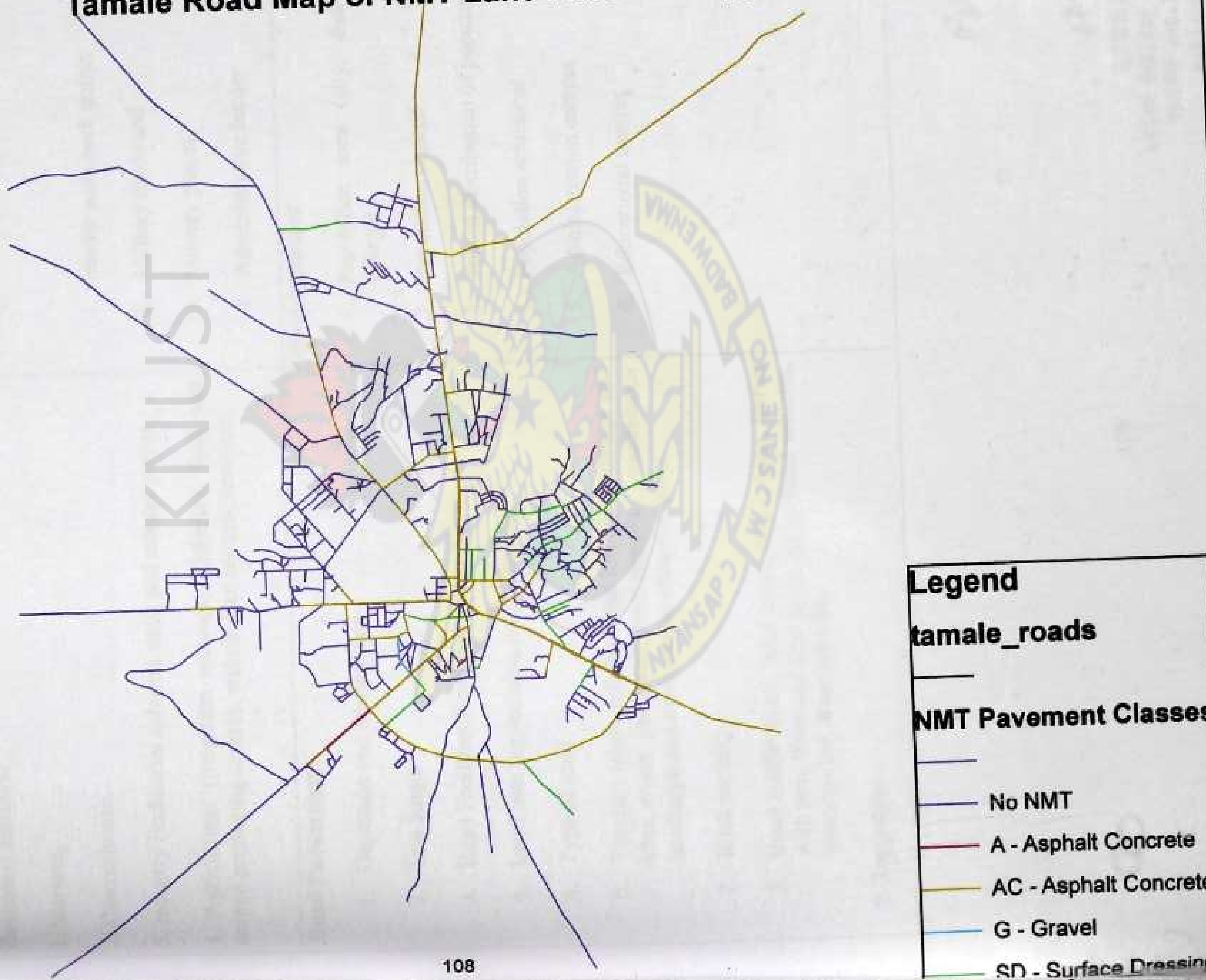
Appendix D6
Tamale Road Map of Roads with NMT Lanes



Appendix D7:
Tamale Road Map of Roads with Drains



Appendix D8
Tamale Road Map of NMT Lane Pavement Types



APPENDIX E

Road Inventory and Decision Support System Tables

Appendix E1: Prioritization Parameters for a Road Management System

Economic Factors:	**Political and Security**
1. Markets, 2. Customhouse, 3. Industry (industrial suburbs, units and storage points, 4. Agriculture: (irrigation networks, fisheries, food and animal producing centres, stakeholder centres, dams etc.	1. Border and check points 2. Military roads and 3. Military places 4. Administrative border
Road Parameters: 1. Departure and destinations 2. Trip length 3. Road Facilities (terminals and services 4. Land use: (agriculture, jungle, pasture 5. Type of road 6. Tourist : lakes, religious and historic buildings and sites, rivers, game and forest reserves, mountainous landscape and other tourist attraction areas 7. Road security 8. Road traffic: (cars, mini buses, buses, vans, lorries with two, three and four axles, agricultural vehicles, motorcycles, other vehicles. 9. Topgraphy	**Human factors** 1. Population area (city, district, village) 2. Population change 3. Spatial distribution of population 4. Population structures 5. Administration centres 6. Educational centres

Appendix E2: Outline the changes in road management functions. (Robinson *et al, 1998)*

		Coverage	Horizon	Concerned
Planning	Define road standards which minimize cost. Determine budget needed to support defined standards	Entire network	Long term (strategic)	Senior managers and policy makers
Programming	Determine the work programme that can be undertaken within the budgetary period	Sections likely to need road treatment	Medium term (tactical)	Managers and budget holders
Preparations	Design of works Preparation and issue of contracts and works instruction	Contract or work packages	Budget year	Engineers, technical and contract staff
Operations	Undertaking tasks as part of works activity	Sub-sections where works are taken place	On-going	Works supervision

Appendix E3: Damage Rating (R)

Unpaved Roads

E \ S	1 Light	2 Moderate	3 Severe
1 <10%	1	3	4
2 10-50%	2	4	5
3 >50%	3	5	5

Paved Roads

E \ S	1 Light	2 Moderate	3 Severe
1 <15%	1	3	4
2 16-30%	2	4	5
3 >30%	3	5	5

Appendix E4: Grouping of Management Systems by Generation

	First Generation	Second Generation	Third Generation
Sectioning	Constant length sections, or fixed length sections based on data collection intervals	Pre-defined, variable treatment lengths based on physical pavement characteristics and traffic	variable treatment lengths obtained by combining defect lengths after analysis for efficiency of undertaking works
Intervention levels	Intervention level based on present pavement condition plus traffic.	Intervention levels consider prediction of pavement condition	Intervention levels based on life cycle prediction of both deterioration and impact on road users
Treatment Options	One standard treatment prescription per section	Comparison of do something and do minimum treatment options for each section.	Consideration multiple treatment options per section
Basis of Economic Analysis	Present cost of treatments	Present and future costs of treatments and benefits to road administration	Life cycle approach to costing and inclusion of benefits to road users
Method of Prioritisation	Ranking based on function of present costs, condition and road hierarchy	Ranking based on cost-effectiveness, with consideration of treatment life, and analysis of deferment options.	Formal optimization of multiple treatment options per section over a multi-year period.

Appendix E5:

A. Ben Shneiderman's "Eight Golden Rules of Interface Design

Ben Shneiderman's "Eight Golden Rules of Interface Design" (Shneiderman, 1997) were

- Strive for consistency
- Enable frequent users to use shortcuts
- Offer informative feedback
- Design dialogs to yield closure
- Offer error prevention and simple error handling
- Permit easy reversal of actions
- Support internal locus of control
- Reduce short-term memory load

B. Codd's 12 Rules for Relational Database Design

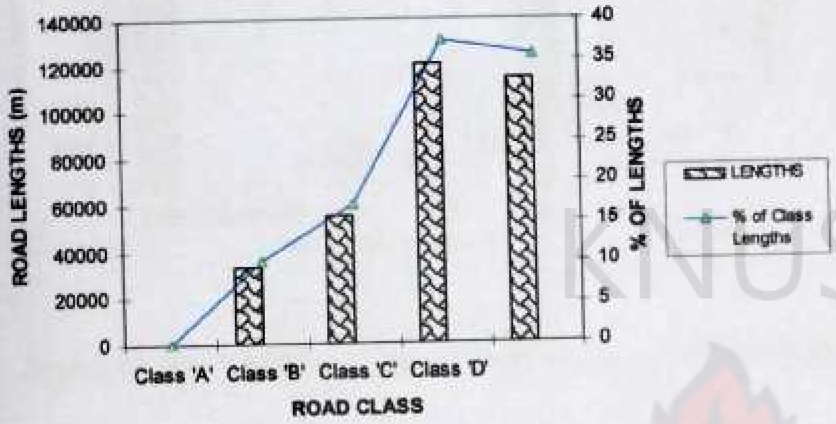
Chapple's Databases Blog citing Codd's 12 Rules for Relational Database Design noted that these rules underpinnings for modern database design

- All database management must take place using the relational database's innate functionality
- All information in the database must be stored as values in a table
- All database information must be accessible through the combination of a table name, primary key and column name.
- The database must use NULL values to indicate missing or unknown information
- The database schema must be described using the relational database syntax

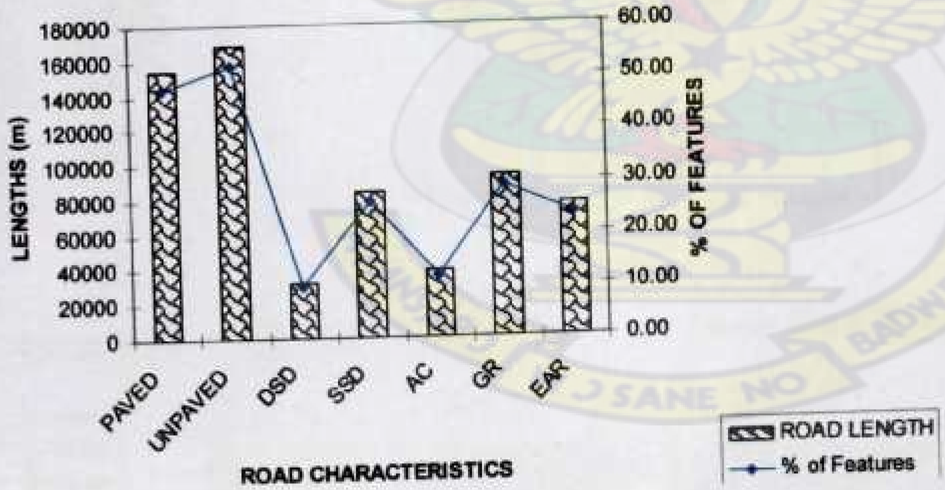
- The database may support multiple languages, but it must support at least one language that provides full database functionality (e.g. SQL)
- The system must be able to update all updatable views
- The database must provide single-operation insert, update and delete functionality
- Changes to the physical structure of the database must be transparent to applications and users.
- Changes to the logical structure of the database must be transparent to applications and users.
- The database must natively support integrity constraints.
- Changes to the distribution of the database (centralized vs. distributed) must be transparent to applications and users.
- Any languages supported by the database must not be able to subvert integrity controls.

APPENDIX F
GRAPHS AND REPORTS

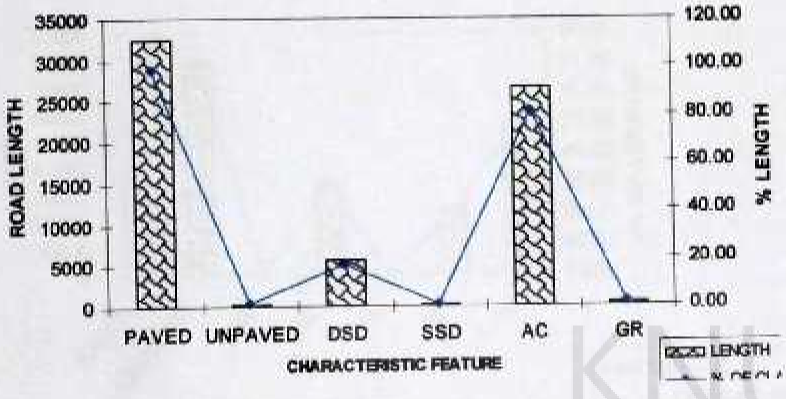
Appendix F1: Graph of Tamale Road Network Class Distributions



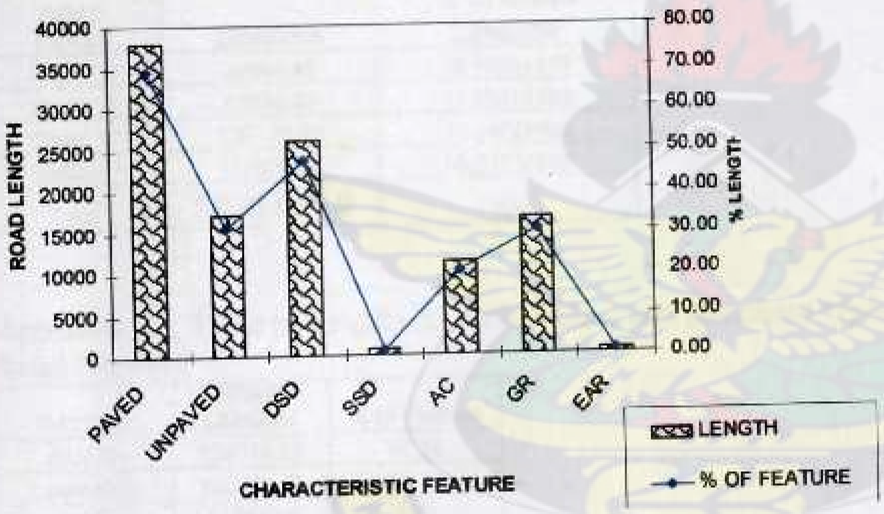
Appendix F2: Graph of Characteristic Features of Tamale Road Network



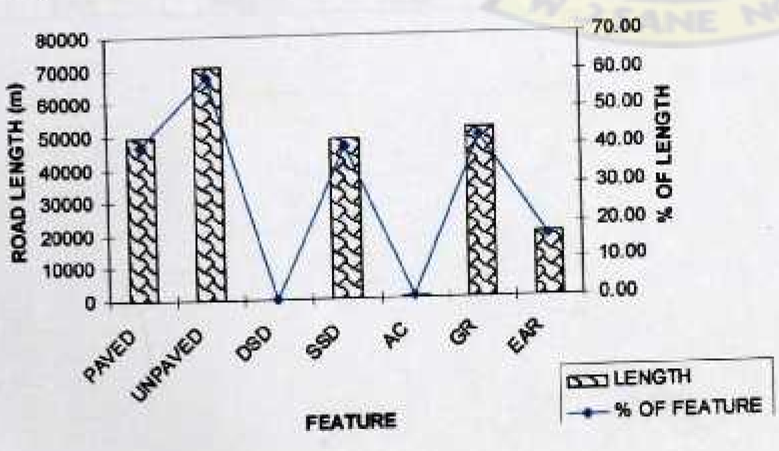
Appendix F3: Graph of Characteristic Features of Tamale Road Network Class 'A'



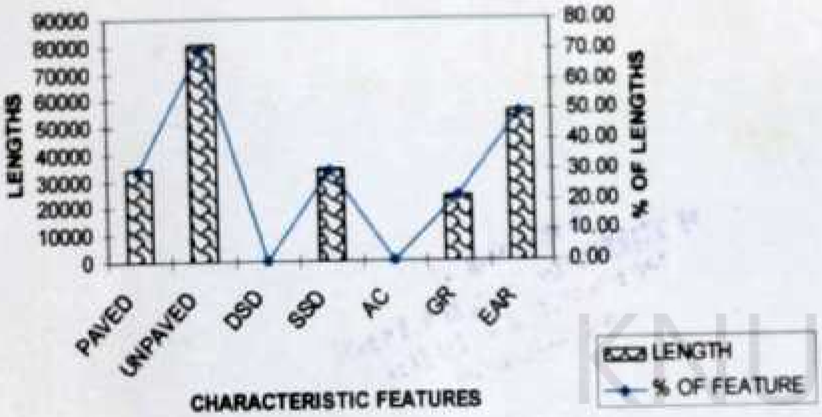
Appendix F4: Graph of Characteristic Features of Tamale Road Network Class 'B'



Appendix F5: Graph of Characteristic Features of Tamale Road Network Class 'C'



Appendix F6: Graph of Characteristic Features of Tamale Road Network Class 'D'



Appendix F6: Table of Road Class lengths within the Tamale Road network

ROAD CLASS	LENGTHS	% of Class Lengths
Class 'A'	32864.43	10.18584176
Class 'B'	55026.88	17.05476383
Class 'C'	120177.56	37.24724905
Class 'D'	114579.28	35.51214535
Total	**322648.15**	100

Appendix F7: Table of lengths of surface class and pavement types within the Tamale Road Network

NATURE	ROAD LENGTH	% of Feature
PAVED	154018.27	47.74
UNPAVED	168486.86	52.22
DSD	31594.29	9.79
SSD	83945.12	26.02
AC	38406.66	11.90
GR	92684.1	28.73
EAR	75805.78	23.49