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**URBAN INFRASTRUCTURE MANAGEMENT USING GEOGRAPHIC
INFORMATION SYSTEMS TECHNOLOGY:
THE CASE OF NAIROBI, KENYA**

Juliana Nasimiyu Wafula

**A thesis submitted to the Faculty of Graduate Studies and Research in partial
fulfilment of the requirements for the degree of**

Master of Arts

Department of Geography

Carleton University

Ottawa, Ontario

April 28, 1994

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**URBAN INFRASTRUCTURE MANAGEMENT USING GEOGRAPHICAL
INFORMATION SYSTEMS TECHNOLOGY: THE CASE OF NAIROBI, KENYA**

submitted by Juliana Nasimiyu Wafula, B. Sc.
in partial fulfilment of the requirements for
the degree of Master of Arts

D.R.F. Taylor

Thesis Supervisor

Iain Wallace

Chair, Department of Geography

**Carleton University
May 25, 1994**

Abstract

The rapid growth of urban areas in developing countries puts extreme pressure on urban administrations and municipalities to finance and manage basic public utilities. The use of effective, economical and easy to use Geographic Information Systems (GIS) in these countries should help improve the management and planning of urban infrastructure. This thesis will investigate the possibility of applying Geographic Information Systems Technology to this task. A section of the city of Nairobi, Kenya will be used to demonstrate the capability of this technology. It will be argued that Geographic Information Systems Technology can do much to help manage and plan urban infrastructure.

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CHAPTER ONE

INTRODUCTION

1.1 Objective

The objective of this thesis is to investigate the applicability of Geographic Information Systems (GIS) technology using the multi purpose approach to managing urban infrastructure data for an urban area in a developing country. A section of the city of Nairobi, Kenya shall be used as a case study.

1.2 Introduction

Land is the basis of all functions of human activity, from which food, shelter and space are obtained and without which human beings could not survive.¹ Land resources are in process of being exhausted and destroyed and definite measures need to be taken to ensure that resources that have taken millions of years to accumulate are not allowed to waste.² It is important therefore that accurate knowledge of existing resources be obtained.³ This situation is especially acute in developing countries where rapid population growth and massive rural to urban migration has led to uncontrolled expansion of urban centres. The result has been deterioration of health and living conditions especially in low income settlements, and a further

degradation of the environment.³ The growth of urban centres in Kenya increased from 17 in 1948 to 240 centres by 1993. Within the last five years, the population in urban areas was expected to increase from 4.0 million inhabitants to 5.6 million.⁴ Since the oil crisis of the 1970s, the economy of the country has been on the decline and has yet been unable to recover. The resistance to recovery has been attributed to the decline of world prices for its exports of tea and coffee, increase in interest rates, foreign debt repayments and a decline in international development aid to say nothing of the burden of increased population.⁵ As a result, urban municipalities are under extreme pressure to provide urgently required basic public utilities and to maintain existing utilities with the diminishing financial resources available for urban infrastructure construction and maintenance. Between 1989 and 1991, capital expenditures on urban area services declined by about 30 percent in Kenya.⁶

Effective and affordable technologies for collecting information and analyzing data have to be put in place to enable better planning and management of urban infrastructure with the available resources. Traditional information systems, usually manually operated, have been used to process and produce reports in tabular form.⁷ These reports have meaning when used with a conventional map to give the data a geographic reference. The disadvantage of using maps is that the amount of descriptive data stored and displayed is limited, and that the data has to be retrieved visually and manually.⁸

³Urbanisation and deterioration of environmental conditions as a result of rapid urban growth are discussed in WHO, Urbanisation and its implications for child health. Potential for action, (Geneva, Switzerland: WHO, 1988)

Geographical information Systems^b (GIS) technology utilises information in digital form so that processing, analysis and retrieval of different data forms is fast and accurate. The technology also has the ability to integrate information from many different sources. This makes GIS technology a suitable tool for efficient planning and management of urban infrastructure.

1.3 Method of approach

The above objective will be demonstrated on a section of the Province of Nairobi measuring 1.4 by 1 km in size as a pilot area that also cuts across the administration boundaries of the Province. PC ARC/INFO and AutoCAD Release 12 software were used for data input and data manipulation, Total Information Management System (TIMS) software for data analysis, and dBASE IV software for attribute data input.^c

Data conversion was done for this area to include parcels (lots), streets, sewers, water pipes, railway lines, rivers, buildings, bridges and administration areas. Anticipated queries were formulated and analysis done on the data to address these. Reports, plots, graphs and charts were also produced from the analysis of the data.

^bGIS technology is discussed in chapter three.

^cTIMS, AutoCAD, ARC/INFO and dBASE IV are trade marks of Object Graphics, Autodesk Incorporated, ESRI Incorporated and Aston-Tate Corporation respectively. The characteristics of these software systems are discussed in chapter four.

1.4 Limitations and assumptions

Not all urban infrastructure elements found in an urban area have been included but the different types of data entities that is points, lines, polygons have been represented. The queries that have been answered may not be exhaustive, but are a representative sample of the capability of the particular GIS software. The design of the database files may not encompass all the necessary variables in a particular area of application but has taken into consideration the different forms of textual data that is associated with urban infrastructure. Detailed data for engineering design has not been totally included in some data layers. For instance, design specifications for manholes are not included. What is included is the reference to the manhole and its location in terms of UTM coordinates.

It should be noted that the emphasis is placed on the different types of data and data attributes that can be handled by GIS but not on what is actually there in reality. Graphic data for water pipes, sewers, roads, rivers, bridges, buildings, parcels was improvised as it was not available. Information in the database files was also improvised in most cases.

This study is used as an example to show the type of data entities associated in urban infrastructure. The few layers of graphical data encompass all the different data structures in an urban area. Therefore this study does not reflect the true situation but rather is a pilot of analysis functions capability using Geographic Information Systems technology.

1.5 Organization

This thesis is divided into six chapters. An introduction to the thesis is given in chapter one. A general outline of the method of approach, limitations and assumptions is also given in this chapter. Chapter two addresses trends in urbanisation and its effect on the welfare of the communities involved. Macroeconomic effects on the provision of infrastructure, its role in the development of urban areas, and problems of managing infrastructure are identified. Chapter three discusses the technology of Geographic Information Systems. A definition of the technology as well as a brief history of the technology is given. Perception of real world data and the introduction of this into the computer is discussed. A critique of the technology and examples of application of this technology to urban management are also addressed.

Demonstration of GIS technology to urban infrastructure management is discussed in chapter four on a section of the Province of Nairobi. The characteristics of the software and hardware used are discussed. Data collection, input and manipulation are described and examples of data analyses with simulated real life situations are done. Chapter five describes the limitations of the study in terms of data accuracy and quality. A discussion of data accuracy and quality is done and the study area evaluated using these concepts. Conclusion and recommendations to this study are given in chapter six.

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CHAPTER 2

URBAN INFRASTRUCTURE

2.1 Introduction

Rapid urban growth as well as reduction of financial resources in developing countries puts extreme pressure on urban authorities to provide basic services. The results have been a decrease in the overall provision of infrastructure services with a deterioration of living conditions especially for the urban poor. This chapter will look at trends in urbanisation and its effects on the general welfare of the communities involved. Macroeconomic effects that affect the provision of infrastructure will be discussed. The role of infrastructure, as a contributing factor, in the development of urban areas will be addressed. Emphasis will be placed on the problems affecting local governments' administrative ability to provide and manage infrastructure.

2.2 Urbanisation

The urban population in developing countries is increasing at a very high rate. The population has grown from about 300 million since 1950 to 1.3 billion in the 1990s with an annual growth rate of about 4 per cent per annum.¹ Several factors contribute towards urban growth in developing countries. Among the three most important are:² the natural increase in urban areas due to natural population growth

coupled with the introduction of modern health care which helped reduce the infant mortality rate especially in countries like Kenya; rural urban migration; and reclassification as a result in the changes in definition of urban areas. Most contribution to urban growth has been due to rural urban migration and natural increase although this varies in different developing countries depending on their stage of urbanisation.³ At the initial stage, migration contributes more to urban growth than natural increase, at an intermediate stage, contributions to urban growth are mostly due to natural increase while at the final stage with high urbanisation and low rates of natural increase, migration again contributes more towards urban growth. A slightly different classification is reflected in the following patterns of urbanisation in developing countries:⁴ countries with more than 75 per cent of their population already in urban areas attribute further growth more to natural increase than migration; countries that are becoming more urbanised recently with 50 per cent of population in urban areas, tend to grow faster as a result of migration from the rural areas; countries with a large percentage of their population in rural areas are rapidly urbanising as a result of rural urban migration; and in countries with highly rural populated centres, growth of urban areas is due to natural growth leading to urban concentration in secondary urban areas. Kenya falls within the third pattern having a large percentage of its population in rural areas but is rapidly becoming urbanised. Table 1 shows the urbanization process in Kenya between the years 1988 and 1993.

Table 1. Rural Urban population distribution in Kenya in millions.

Year	1988	1989	1990	1991	1992	1993
Urban	4.0	4.3	4.6	4.9	5.2	5.6
Rural	18.7	19.2	19.8	20.4	21.0	21.6
% urban to total	17.6	18.3	18.9	19.4	19.8	20.6

Source: Ministry of Planning and National Development, Kenya, National Development Plan for the period 1989 to 1993, (Nairobi: Government Press: 1989) table 5.1

Rapid urbanisation growth in Kenya started only after the second World War.⁵

This is shown in table 2 for the years 1948 to 1993.

Table 2. Urban growth for the years 1948 to 1993

Year	Urban areas	% change	Pop. in millions	% change
1948	17		0.276	
1969	48	182.4	1.08	291.3
1979	67	39.6	2.3	113.0
1988	172	158.2	4.0	73.9
1993**	240	39.5	5.6	40.0

****Projected**

Source: Adapted from Ministry of Planning and National Development, Kenya, National Development Plan for the period 1989 to 1993, (Nairobi: Government Press, 1989) p.74

From table 2, it can be seen that there is a remarkable increase in the number of urban centres since 1948 which has contributed to the overall urbanisation process.

Because of the importance of the contribution of migration to the urbanization

process, a brief discussion of the factors causing migration will be given together with the effects of migration on the urban communities involved.

2.2.1 Reasons people migrate

A major reason why people migrate is their desire for better employment opportunities, social facilities, and access to education that are not available in their place of origin. Since the process of migration is strongly related to employment opportunities, factors affecting the location of employment opportunities need to be considered and include: agricultural development, industrial and economic development and the development of transport and communication facilities.⁶ Rural areas in some cases can no longer sustain their growing population because of a decrease in agricultural output that in some instances is caused by natural disasters like drought, floods or invasion by locusts. The increase in population in rural areas poses a heavy burden on the capability of the land to support its growing population. In Kenya for instance, due to rapid population increase in Central Province, land holdings have been subdivided into smaller and smaller units in the process of inheritance leading to holdings which are no longer capable of sustaining their owners. Industrialisation and related economic development are mainly centred in urban areas because of a variety of factors including the existence of large consumer markets. The presence of financial institutions helps stimulate growth and investment. Urban areas offer markets for industrial products at low cost in terms of transportation and ready markets for the consumption of goods. The existence of transportation and

communication facilities in urban areas encourage potential investors to the area.

2.2.2 Social consequences of migration

Most migrants in developing countries are young males who leave behind their families in the rural areas.⁷ The absence of the migrant leaves the family short of a labourer for agricultural production. This poses an increased burden on the remaining members of the family, women and children, who have to work harder to keep up with the level of production. The absence of the husband means there can be more food to go around and in the case of the wife, she often becomes a head of the household making vital decisions and in some instances gains a certain social status. However, if the family was initially incapable of supporting itself, the absence of her husband may make the wife and children dependent on her in-laws.

Remittances from the migrant to the rural areas help improve the standard of living and thus compensate for the loss of the income and contribution.⁸ But this may increase the reliance on hand outs from the migrant thus discouraging the stimulation of the rural family's ability to produce.

Ideas and knowledge procured by the migrant and contacts established are transferred to the rural areas.⁹ For example, many migrants tend to construct modern homes and improve the water supply in their rural homes.

The absence of spouses leads to emotional and personal problems both for the spouses and the children. A decrease in fertility due to delayed marriages in single migrants and postponed child bearing in married migrants is common.¹⁰

2.2.3 Economic effects of migration*

The rise in urban population creates a demand for rural produce. Because of the rising costs to produce these commodities, the rural economy is stimulated as the production prices often rise in response to increased production costs caused by labour shortages at critical harvest and planting times. On the other hand, the effect of migration on the rural areas is that agricultural production may decline as a result of labour shortages. This may be partially offset by the use of labour saving technologies and improved farming methods.

The majority of migrants are normally people with a lower level of education and skill than the average urban dweller. This makes it difficult for them to find employment and thus money to pay for accommodation and food. There is thought to be an increase in unemployment and underemployment in the urban areas because of the increase in the size of the available large labour force. This, on the other hand, may encourage urban investment because of the increased availability of cheap labour. Migrants are people who have come to seek a better life and so will often take the available jobs and work hard to improve their standards thus stimulating the urban economy.

The large number of migrants increases the demands for infrastructure

*The effect of migration on the economic situation in developing countries has been adapted from A. S. Oberai, "Migration, Urbanisation and Development," World Employment Programme, 5, (Geneva, Switzerland: International Labour Office, 1987) and Ajit Singh, "Urbanisation, Poverty and Employment: The Large Metropolis in the Third World," World Employment Programme, 165, (Geneva, Switzerland: International Labour Office, 1989), microfiche.

facilities and social services. The access to these by the poor migrants is limited and thus their living standards are often appalling. For example, the rapid increase of population leads to the growth of slums and squatter settlements as the high costs of the existing accommodation is only affordable to a small proportion of the population. Natural population distribution and the patterns of economic growth tend to be unbalanced as a result of migration because most of those who migrate are able bodied men leaving behind the old people, women and children in the rural areas.

The high concentration of population in urban areas may lower the overall national cost of providing services. It is more economical to construct facilities to serve large populations than to serve few individuals.

The poor provision of housing and transportation facilities in urban areas is due to the inability of local government to provide and maintain existing infrastructure. The urban environment often deteriorates due to increased industrial pollution and the effect of increased vehicular traffic. Breakdowns of water supplies and sanitary services also contributes to the deterioration in living conditions. Some problems created by poor housing, sanitary and water supply are:^b

- lack of access to clean drinking water increases the spread of typhoid, hepatitis, dysenteries and other water borne diseases.
- lack of proper sanitary facilities leads to the transmission of food related and water related diseases or intestinal infections like hook worms, tape worms and ring worms.
- insufficient water facilities for cleaning result in skin disease such as scabies.

^bFurther details on effects of urbanisation are discussed in WHO, Urbanisation and its implication for child health, (Geneva, Switzerland: WHO, 1988)

- inadequate availability of housing often result in the construction of poor houses made from cardboard or paper. These houses are often occupied by many people. These facilities are hazardous because when a fire starts the whole place is totally devastated.
- cockroaches and mice are common in these areas. The spread of infectious diseases like meningitis, mumps and measles due to human contact is accelerated because of the squashed and constricted living space.
- lack of open spaces for children to play in result in children playing in the streets which can lead to accidents.
- sites of these homes are normally along river banks and these areas are usually prone to floods and mud slides.
- lack of access to emergency services like telephone and hospitals as the establishment of these are normally in areas with permanent housing structures.

These problems require urgent measures by the local governments to provide basic amenities, improve the nutritional level of the population and build administrative frameworks at the local level, and to obtain capital to pay for the development and maintenance of basic infrastructure.

2.3 Macroeconomic issues

Post World War II development theories identified industrialization as the key to developing the economy of a country.¹¹ To help initiate and sustain industrialization, governments invested in the development of infrastructure. The success of this theory in Western Europe led the policy makers to apply these theories to developing countries. Donor countries installed projects in developing countries that often could not be sustained because of the rapid growth of population and poor policy

formulation at the time of implementation.¹² By the mid 1980s, a reduction in export goods, a fall in prices of these commodities on the world market, an increase in foreign debt repayment and a reduction in international aid meant that many developing countries could not sustain their infrastructure.¹³

The impact of these macroeconomic developments was that governments were unable to keep up with transfer payments to the local authorities that were charged with the responsibility of providing the infrastructure services. Table 3 shows the expenditure and revenue of municipalities for the period of 1985 to 1991 in Kenya.

Table 3. Expenditure and revenue in Kenyan thousand shillings. (1000 shillings is approximately 20 Canadian dollars)

Year	85/86	86/87	87/88	88/89	89/90	90/91
Expenditure	150,153	125,161	139,311	146,541	248,442	172,880
Revenue	114,654	107,170	117,972	146,755	228,531	182,467

Source: Central Bureau of Statistics, Statistical Abstract, (Nairobi, Kenya: Central Bureau of Statistics, 1991) tables 206(a), 206(b), 208(b) and 209(c)

Between the years 1989 and 1991, capital expenditure on municipal services declined by 30 percent although there was an increase between the years 1988 and 1989 as can be seen from the table. At the same time, basic infrastructure services are priced low in order to provide benefits to as many people as possible but these do not cover the real cost of the services and agencies supplying these, are unable to maintain and operate the services without the central government transfer payments.¹⁴ Lack of coordination between the concerned public agencies as well as poor policy formulation which does not take into consideration the requirements and special circumstances of

the urban poor, contributes to the inability of the administration to provide and maintain infrastructure.¹⁵

2.4 Solutions

Since concentration of population in a few urban centres is inevitable, the solution is to introduce better management techniques and policies to help alleviate problems caused by urbanisation.¹⁶ For instance, if pollution from vehicles is a problem, the number in the city centre should be reduced encouraging people to use bicycles and the public transport system. Another solution is to decentralize activities from the major cities into smaller urban areas by making these attractive to potential migrants.¹⁷ This is done by establishing policies aimed at stimulating the rural economy; encouraging the development of smaller towns; and curbing the expansion of the larger cities by controlling migration.

The Government of Kenya's strategy for human settlements has the aim of increasing the rate of urbanisation while ensuring that this occurs in the smaller urban centres.¹⁸ The plan is to stimulate economic growth in the smaller towns of population 2,000 to 20,000 to a growth rate of 7.5 percent. To facilitate this, certain incentives were planned which included channelling of resources to smaller urban areas by making available the necessary financial and physical infrastructure, and restructuring local authorities in the areas of management and financial control. Financially this was to be done by establishing a Municipal Development Bank and introducing user charges to provide a financial base for the local authorities. The

establishment of Rural Trade and Production Centres (RTPCs) to provide markets and outlets for agricultural produce was to encourage economic activity in the smaller urban centres in rural areas. This development was to go hand in hand with developments in basic infrastructure both within and without the urban centres. While realising that centralisation of management of resources and planning has been inefficient, decentralisation of services was carried out because problems faced by local authorities could only best be understood and attended to by the local authorities themselves. Local authorities were given more autonomy to manage and plan for their own activities. To realize these goals, an 'integrated approach' to planning was adopted in the Sixth National Development Plan.¹⁹ This

'entails viewing development issues inter-sectorally such that a set of issues is addressed at the same time by all sectors in search of solutions and priority given to major issues facing the country, including improved management of available resources...and enhancement of public welfare.'²⁰

However before this plan can be effective, the government will need information about interactions between macro and micro economic policies and their effect on infrastructure services.⁶ A conceptual frame work for monitoring and supporting economic and social analysis and capabilities of local government needs to be identified.²¹ Equitable treatment of all people is important in the economic efficiency of infrastructure because this will dictate where resources should be

⁶A discussion of the role of the government in formulating policies that enable access to services by the poor is discussed in United Nations, Habitat, Global Strategy for shelter to the year 2000. Implementation of the first phase, (Nairobi, Kenya: Habitat, 1991).

mobilized in order to benefit the needy groups.²²

The next section will look at the role infrastructure plays in development of an urban area. The activities, nature and problems within municipalities as regards infrastructure will be addressed. Areas where GIS technology can be applied will be identified. Although many factors are involved in creating an urban environment that takes into consideration factors affecting the urban poor, the main concern, as a backbone to all these, is the development, construction and maintenance of infrastructure.

2.5 Infrastructure

Although the word infrastructure has been used before, a proper definition is now given. Infrastructure is a term associated with public works and physical facilities. Public agencies develop or acquire infrastructure in order to provide basic services necessary for the health and well being of the community.²³ Urban infrastructure therefore would be the services that allows urban dwellers, especially the urban poor, to live in conditions that will encourage their participation in income generating activities.²⁴ Infrastructure facilities vary from urban area to urban area but include the provision of piped clean drinking water, sanitation, solid waste disposal, transportation, and housing facilities.²⁵

2.5.1 The role of infrastructure

Local authorities should see infrastructure as a source of generating income to finance their projects. Previously, the revenue base of local authorities in Kenya was affected when the government abolished the Graduated Personal Tax in the 1973.²⁶ At the same time, the elimination of primary school fees and the shifting of the responsibility of primary education to local authorities affected the resources of these local agencies. The major source of revenue became the property tax that was only collected on the unimproved value of the property.²⁷ Because of this, cuts in public expenditure affected the infrastructure services as budgets for maintenance, supplies and operation of infrastructure could not be sustained. The introduction of user fees can help generate income for the local authorities to enable them maintain, operate and construct infrastructure. Construction of infrastructure also can help create jobs for the unemployed people in the area.

The success of an urban area is influenced by infrastructure facilities.²⁸ Infrastructure development is tied to the health and welfare of its people. People need transportation to get to work and to engage in income generating activities. For instance, a good transportation system will enable goods to reach their destination in time and in good shape.

Poor infrastructure services lead to poor people having to look for services elsewhere. Since they do not have a strong political voice and lack economic power, poor people do not get access to the available but limited resources.²⁹ The lack of basic housing in urban areas encourage the mushrooming of slum areas. There is a

potential for people to exploit the poor in terms of providing basic facilities at higher prices. For example, private vendors distribute water in the low income areas at prices higher than those paid by the rest of the populace.

The effect on the environment due to lack of basic infrastructure is appalling.⁴ Poor cooking methods and home lighting appliances are fire hazards. Fumes produced from the fuel used in cooking or the fire wood leads to an increase of respiratory diseases especially among the young children. Where there is lack of sanitary services and solid waste disposal, the solution is to pile it up outside the home or flush into the river that people also draw from for cooking and washing.

2.5.2 The role of Municipalities

Municipalities are created through government legislation to provide basic services that are necessary for the development, growth and welfare of their residents.³⁰ Central governments use local governments to manage and provide the required services to the residents. Local authorities in Kenya are organized into municipalities, town, urban and county councils. Each municipality will have a different mandate depending on the resources at its disposal, location, weather and size of population but generally it has common activities.³¹ The activities in a municipality include the maintenance of roads, sewers, water pipes, properties, parks, and health centres. An inventory of these services is kept and the planning of future

⁴A discussion of the effects of urbanisation on the environment is discussed in WHO, Urbanization and its implications for child health. Potential for action (Geneva: WHO, 1988)

allocation of these services is carried out. Administrative and social services to provide basic education and health centres are other activities.

The Municipality is divided into departments and sectors that have responsibility for providing the services listed above. Although detailed information as to how municipalities are organised in Kenya was not available it is thought to follow along the same lines as City Of Ottawa.²² The Engineering and Works department in the City of Ottawa is divided into four divisions. These are design and construction; needs, planning and budgeting; environmental and administration services; engineering development and services. In the design and construction division, design and tendering out of contracts is done. Also examined are the specifications of the structures after the construction is complete. The division of needs, planning and budgeting integrates activities between departments, maintains inventories, analyzes data, prioritizes the construction and maintenance of services, and advises on major undertakings. The Environmental services division manages sewers and storm water facilities. The Administration division develops policies, monitors the budget and spending, and assesses the performance of the divisions. General administration, human resource management and development issues are also managed by this division. The engineering development services division controls and plans facilities within the city's right of way and processes applications for sewer construction, private approaches and development of private property.

2.5.3 Nature of infrastructure data*

Spatial features within an urban area include points, lines and polygon or areal type features. Manholes, street lights and fire hydrants are examples of point type features. Linear type features would include streets, networks, paths and rivers. Polygon or areal type data would be buildings as depicted in two dimensions, parks, administrative boundaries, and parcels boundaries that may be invisible. Data stored on a manhole would include its location with respect to a coordinate system, its type, date of construction, reference to its design specifications. Data stored for networks would include the beginning and end of the elevation of the pipe, the direction of the flow, the length of the pipe and type of material used in construction. Data on streets would include the name of the street, references to long sections and cross sections, and design specifications. Data on land use would include the type of activity carried on there, the zoning area, and the potential of the land for development.

This information is stored in form of plans or diagrams or in textual form in manual registers or reports. Data on maintenance of these structures is also stored on the maps and plans. The information is kept in different locations, the maps or designs in a separate drawer, and the textual information in another place. An indexing system is used to locate information pertaining to a feature.

*Nature and problems with infrastructure data are adapted from J. M. Rector, "Utilities," in Profiting from a Geographic Information System, ed, G. H. Castle, III, (Fort Collins, Colorado: GIS World Inc.,1993) pp. 193-208.

2.5.4 Problems in infrastructure data

Most of the records on infrastructure are portrayed on maps or plans. The problem with maps is that they can be inaccurate, congested and illegible. Errors shown on maps could include the location and identification of map features. For instance, a map may show a building has three floors instead of four. The updating and correction of maps take a long time if done manually. Most of the updating is done only when a project is complete. A street, for instance, would not be shown on the map until construction was completed. This makes it more difficult to follow the progress of the construction work.

Record and reports are produced occasionally for the infrastructure. These take considerable time to prepare especially if the report was required with specific criteria. If the City wanted to know the pipes made out of clay, a clerk would have to comb through all the information which could be in different locations in order to prepare the report.

At the end of the fiscal year, reports and records for budget proposal and planning activities are often required. The preparation of these takes a long time and requires considerable input from different departments.

Planners require city layout plans tied to geographic locations or areas because these aid in portraying future development patterns with respect to other features. New zoning changes requires the plans redrawn again and this not only is time consuming but also results in duplicating of data.

For daily or regular maintenance, work orders are required and preparation of

these is time consuming if done manually. For instance to show the section of the road to be worked on a particular day requires that this information be extracted from the plan. The draughtsman redraws the plan and shows on it the area that requires maintenance. This results in duplication of data as only the area to be worked on should be produced.

Different departments in the municipality require to integrate their information. For instance, the planning department produces land use maps or zoning maps and would like to see how the planning correlates to the street infrastructure. Manually one data set is overlaid onto the other or redrawn with one acting as the base. This not only takes time but also introduces errors in the final result.

A Master Plan may be required by more than one user. Because of constant use the map quality, that is the cleanliness and appearance, can deteriorate with usage and time. Also certain users will have to wait their turn to get access to the plan.

Most municipalities are constrained in terms of personnel and financial resources. Documentation of records of services and present state of the facilities will aid in identifying priority areas. For example, clerks will need to peruse manual registers to identify houses connected to clay sewers of diameter 200 millimetres. Consumers affected will also have to be identified and this again will have to be researched for the different sewers.

Organization within the municipality or department is hierarchical. The engineer at the bottom of the hierarchy cannot directly interact with the planner without going through the top personnel. Duplication of data may occur sometimes

because it may be easier for departments to collect their own data than to borrow it from other departments.

Most departments have their own mandate and their own set of rules governing data collection and processing. For instance, the planning department may have plans prepared with the smallest data resolution being the parcel. The water maps or networks may be prepared to the resolution of the main water distribution points. These sets of data cannot be integrated because the data is at different resolutions.

2.6 Characteristics of required systems

Manual drafting and map production need to be automated so that revisions and updates of maps are fast and more accurate in terms of data content. Systems should be able to handle data at different scales and resolutions. Data input of engineering plans, normally at large scale, should be as simple as input from small scale maps. Charts and graphs form an essential part of data for local authorities and a system that can handle these will reduce the preparation times.

Facilities to perform spatial queries will aid in setting priorities and to projecting future needs. Simple queries from the public especially should be answered as quickly and as accurately as possible. People may call to ask or complain about lack of water in their areas. A system that can quickly pull out the list of names so that the people concerned and the location of the water pipes determined will enable action be taken immediately.

Systems that act as inventories to store textual data and to link textual data

with graphic data will be an extra benefit. Data collected within the municipality comes from different sources so systems should be able to integrate this data.

The development of computer based Geographic Information Systems technology will enable data collected to be analyzed for the management of infrastructure.³³ GIS technology can help determine areas that need public policy and also analyze the success of the policy goals.³⁴ Since Geographical Information Systems (GIS) process data in digital form, data can be updated, edited and viewed before being produced on paper. GIS has the capability to integrate data from different sources and to also link graphical and textual data. The most powerful feature of the GIS is its ability to do spatial analysis. Bearing in mind that an 'integrated approach' to solving issues is important, a multipurpose approach to GIS will be adopted.

Although, many factors are involved in the maintenance of an urban infrastructure, what is of major concern in this thesis is the ability of GIS technology to address issues in urban infrastructure management. The next chapter will describe this technology. It will look at the components of GIS, the nature of geographic data and integration of these into a GIS. A critique of the technology is given at the end of the chapter.

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CHAPTER 3

GIS TECHNOLOGY

3.1 Definition

Geographical Information Systems or Geographic Information Systems (GIS in short) are terms that are applied to geographically oriented computer technology and integrated systems used for quantitative and qualitative spatial analysis applications.¹

There is no simple, all purpose definition of GIS in particular,² but it can generally be defined as:

[consisting] of computer software, hardware and peripherals that transform geographically referenced spatial data into information on locations, spatial interactions, and geographical relationships of the fixed and dynamic entities that occupy space in the natural and built environments².

GIS can also be defined in structural terms by what it is, or in functional terms by what it does.³ A structural definition would define GIS as having data, databases, software, hardware, peripherals, and liveware.⁴ A functional definition would see GIS as providing tools for acquisition, editing, management, analysis, modelling, display, output and dissemination of data.⁵

Generally, it can be said that GIS is a computer based tool that can perform the

¹Different definitions of GIS technology are given in D.J. Maguire, "An overview and definition of GIS," Geographical Information Systems. Principles and Applications, eds. D. J. Maguire, M. F. Goodchild and D. W. Rhind, (Essex, England: Longman Scientific and Technical, 1991), vol. 1 pp. 9-20.

⁴Liveware refers to the people responsible for the design, implementation and application of the technology.

following tasks: input, storage, retrieval, manipulation, analysis, and output for both spatial and non spatial data.⁶

3.2 Development of GIS technology

GIS technology has evolved mainly through interactions between the professions of cartography, computer science, surveying, geography, remote sensing, commercial data processing, statistics, and mathematics.⁷ Although the development of GIS began in the early 1960s, the technology was not fully exploited because the available resources then could not accommodate the spatial nature of geographic data.⁸ The input and output devices that existed were not sophisticated enough to deal adequately with the spatial resolution required for geographic data.⁹ Reasons for early GIS development during the 1960s varied and ranged from curiosity, experimentation with different data sources, speed in some geographic data operations created by new technologies, to using GIS to do spatial analyses that otherwise would not be possible.¹⁰ One pioneering project of GIS development in North America was the Canadian Geographic Information System sponsored by the Canadian Federal Government in the mid 1960s.¹¹ The system utilised data from the Canada Land Inventory (CLI) to produce information for land capability for forestry, wildlife, agriculture and recreation. The Land Use and Natural Resources Inventory (LUNR) of New York state was also a GIS developed at the same time as the Canadian Geographic Information System.¹² LUNR utilised existing map and aerial photographs to map and process resource information. These projects initiated more

interest in GIS development.

In 1976, the Minnesota Land Management Information System (MLMIS) was started as a research project within the University of Minnesota, Centre for Urban and Regional Analysis.¹³ It was based on digital land use map of the state that had been prepared from aerial photography.⁵ Within the academic arena, the Harvard Laboratory for Computer Graphics developed the SYMAP, GRID, and IMGRID software that became the first to be widely used for map overlay functions. In the United Kingdom, the Experimental Cartographic Unit was also involved in the research and development of GIS technology.¹⁴ Although these early systems were generally concerned with natural resource applications, their development provided experience on management and operation of large Geographic Information Systems.¹⁵

The rapid development of computer technology and reduction in price of computing costs within the last two decades speeded the development and use of GIS technology from government agencies and research facilities to the commercial community.¹⁶ Development of desktop hardware and software in the late 1980s and the increase in the availability of digital data stimulated the use of GIS technology within the commercial setting.¹⁷ The GIS systems of the 1990s are expected to be user friendly and be part of integrated systems to support high technological uses and meet the needs of individuals at the desktop.¹⁸

⁵Details of the applications of MLMIS are discussed in A. Robinette, "Land management applications of GIS in the State of Minnesota," in Geographical Information Systems. Principles and Applications, eds. D. J. Maguire, M. F. Goodchild and D. W. Rhind, (Essex, England: Longman Scientific and Technical, 1991), vol. 2 pp. 275-283

3.3 The nature of geographic data

Geographic data is the measurement of the locations of objects within a specified coordinate system on the surface of the earth and the collection of the attributes of these objects.¹⁹ Four components of geographic data have been identified: positional data, attribute data, relationships and time.²⁰ Positional data refers to the unique geographic location for an entity⁴ specified within a coordinate system. Five types of information for positional data have been identified:²¹ the identifier of the entity, the behaviour of this entity, the character of the entity, the position on the surface of the earth and the spatial properties of this entity. For a manhole number 3, the identifier is number 3, the character of this manhole would include information on its size and depth. The position of this manhole would be recorded by X and Y coordinates of its centre with respect to a coordinate system. The spatial properties of this manhole would be determined by its relationship to water pipe sections connected to it and its behaviour or role as it forms part of the water pipe network.

Attribute data describes the entity and can be classified into quantitative and qualitative data.²² Qualitative data describes what the entity is, for example a water pipe network would have pipe section as its basic entity. The quantitative data

⁴An entity is described as a phenomena that can not be subdivided and is referenced by an identifier. It can be a mappable feature like a house or a tree or a conceived unit for imagining but having no real existence. Objects and features are terms used interchangeably with entity. This is discussed further in R. Laurini and D. Thompson, Fundamentals of Spatial Information Systems, The APIC Series, no. 37, (San Diego: Academic Press, 1992), p. 62

describes the properties of the entity. Quantitative data can be further divided into three categories: proportional, interval and ordinal type data. Proportional type data is referenced to a starting point. The length and the width of a water pipe are examples of proportional data referenced to zero on the measuring scale. Basically, interval type is a classification measure. A simplistic example would relate income: personal or household income classified into high, middle class and low by defining ranges of income for each category. Ranking of values within a data set would be an example of ordinal data.

The third component of geographic data is the spatial relationships between entities.²³ The relationship of parcels(lots) to the city blocks would constitute a spatial relationship. For any entity, it is important to know its situation with respect to other entities around it.

The last component and one that is often ignored is time. This serves as a basis to record activities, for observing changes that have occurred and for recording occurrences of an entity.²⁴ Maps covering the same area or purpose can be produced at different times and conditions. Knowing the time can alert the user to the reliability of the map and also recording of occurrences of events makes it easy to trace the history.

3.4 Representation of real world data

The real world is made up of entities representing different elements and relationships that exist within an area. The urban area includes entities like streets,

bridges, houses, trees, water pipes and sewers. These entities need to be represented in a way that will aid in storing, analyzing and studying the relationships between them. Maps have always been used as the media for recording, calculating, displaying, analyzing and understanding relationships of spatial objects.²⁵ The advent of remote sensing^a technology has meant that images are now also used for recording, displaying, analyzing and to some extent understanding the relationships of spatial objects.²⁶

Human beings look at geographic space in different ways depending on the circumstances and area of interest. A surveyor would see an area in terms of boundaries described by distance and bearing between corner points; a social scientist would see the same area in terms of social interactions between the different groups of people; a developer would look at the same area and see its potential for construction of more buildings and structures. All these different concepts and the formalisation of space constitute spatial data models.²⁷

Spatial data models are used to represent the spatial component of geographic information. Two kind of data models have been identified namely vector and raster data models.²⁸ Spatial data in the vector model is represented by combinations of points, lines and polygons positioned with respect to a coordinate system. A point may represent a road intersection, a tree or a manhole and is recorded by its X and Y

^aRemote sensing is the collection of data about entities by use of sensors not in contact with the entities. A discussion of the technology can be found in John A. Richards, Remote Sensing Digital Image Analysis. An Introduction, second, revised and enlarged edition, (Berlin, Germany: Springer-Verlag, 1993)

coordinates. A water network is represented by a network of line entities that are recorded by a series of X and Y coordinates. Polygons, which are closed lines, would represent features of areal characteristics like parcels, boundaries and footprints of buildings and are represented by a set of X and Y coordinates. Geographic data can be represented precisely with this model type.

Three variations of vector data models have been identified. They are: spaghetti, topological and the triangular irregular network models(TIN).²⁹ The spaghetti data model is a file containing spatial data described with coordinate strings. The relationships between features represented by this model are not encoded. For example, in figure 1(a) below, the computer cannot tell that the polygon A is adjacent to B, although it will store the coordinates of the points describing the polygon.

Figure 1(a). Spagetti structure

Figure 1(b). Topological structure.

The topological model stores coordinate strings of spatial data and the

relationships between the data entities. The points are also called nodes and can be end nodes or intersecting nodes. In figure 2(a), A1 to A3 and B1 to B3 are nodes, b1 to b3 and a1 to a4 are lines¹, and A and B are polygons. The relationships between these nodes, lines and polygons are recorded and stored in the computer data base. For example, the lines, arcs or segments are identified by a starting node, an end node and intermediate nodes that describe the shape of the segment. Polygons to the right and left of the arc are also identified.

The triangular irregular network (TIN) is another vector based topological model used to represent terrain data. The terrain surface is depicted as consisting of a set of irregular triangles with this model. The vertices of each triangle are recorded as X, Y and Z coordinates while the slope and aspect of the triangle are stored as attributes.

In a raster data model, geographic space is divided up into grid cells. Historically and currently, square grids have been used, but experiments with triangles and hexagons are now being done.³⁰ The problem with the triangle and hexagon is that the numbering system is complex and the cells, when subdivided further, do not yield the same shape as the original cells. The location of an entity, in the square grid, is defined by the rows and columns occupied. A line entity is represented by a chain of grid cells; a point entity is represented by a cell; and areal type entities by a group of cells which may have the same attributes. Runlength encoding and quadtree structures compress neighbouring cells of the same value to reduce storage space.³¹

¹Segments or arcs are also used interchangeably for lines.

The choice of which data model to be used in representing spatial data will depend on the nature of the data to be collected, the processing and storage and the use to be made of the data.³² The advantages of using vector data structures is that they form a more compact structure for representing graphic data while boundary presentation with raster models is not well defined because of the nature of the grid cells.³³ Simple analysis like overlays with the vector structure are time consuming and require more computer space.³⁴ It has been argued that comparison of map overlay operations, between raster and vector models in modern GIS, is difficult because an efficient method of determining the locations of polygons using an indexed data base is now done with the vector structure.³⁵ Modern GIS now provide the ability to transfer between the two structures although loss of detail is to be expected during the process.³⁶

Urban data is normally required at large scales because accuracy of the location of the features on the ground is important. This makes the vector data model the best data model for use in representing urban data although raster data could be introduced to aid in analysis. For an urban environment, images of important buildings can be attached to the entity of the building for better visual effect.

3.5 Data input/capture

This section looks at the different sources of geographic data. The conversion of geographic data into digital form and the incorporation of this data into a GIS is also discussed.

3.5.1 Data sources

Two different types of data sources for GIS have been identified as analogue and digital.³⁷ The most important analogue data sources for graphical data have been maps. Maps are abstractions of reality as seen and prepared by cartographers using a set of principles to convey intended messages and information. The cartographer determines the scale of the map, features to be generalised, exaggerated or simplified.³⁸ Other forms of analogue data include photographs, diagrams, engineering and architectural plans.³⁹ Documents in manual registers and files, including scientific and technical reports, and survey measurements in form of coordinates are sources of analogue attribute data.⁴⁰

Digital data sources are largely based on satellite technology.⁴¹ These include remote sensing images and position data from Global Positioning Satellites(GPS).⁴ Attribute digital data can be obtained as computer files from database files in dBASE IV, ORACLE and data from spreadsheets from LOTUS and Excel software.

3.5.2 Data Conversion

GIS requires digital data for manipulation and analysis therefore data existing in analogue form needs to be converted to digital form in order to incorporate it into the system. Five ways of producing digitised graphic data have been identified.⁴² These ways include digitising from existing maps, scanning existing maps, digital

⁴GPS satellites were introduced in 1973 by the US military to provide information of positions on earth.

photogrammetry production, manual entry of coordinates and transfer from existing digital sources.

Digitising is the process of creating maps in digital form by encoding data in a form that the computer can read and manipulate into a GIS.^{43b} A map is placed on a digitiser, also known as a digitising tablet, which has a grid of wires embedded in it. These wires produce electromagnetic fields that form a pattern when activated by a cursor¹ placed over a feature on the map. The position of the cursor is recorded in the digitizer's coordinate system. Registration is done to correlate the map coordinate system to the digitising tablet system by use of control points identified on the map and whose ground coordinates are known. Digitising is a tedious process but the concepts are easily understood and thus operators require little training.

Scanning from existing maps involves the use of a scanner. Two types of commonly used scanners are the drum and the flat bed. The map is mounted on a cylindrical drum in the drum scanner and for the flatbed scanner, it is placed on a flat base. The map surface is divided into pixels and a value of brightness for each pixel is recorded by the scanner. Scanning is much faster than digitising from existing maps but requires trained operators.

^{43b}The process of digitising is further described in K. C. Clarke, Analytical and Computer Cartography, (Englewood Cliffs, New Jersey: Prentice-Hall, 1990) ch. 4

¹A cursor is a magnifying glass with a cross hair used to locate and point at features.

Graphic information from surveying work¹ can be manually entered at the keyboard. Coordinates of features, distances and bearings of a property are examples of data from surveying work. Positions of features entered by coordinate geometry (COGO) are accurate but the exercise takes long and is expensive.

Photogrammetry² technology is also used to produce data in digital form. Two overlapping aerial photographs of an area are taken. Rectification is done to these photographs to remove errors and orientation done to relate them to a map coordinate system. The photographs are viewed in three dimensions in a photogrammetric plotter and the features traced using a floating mark or a point. In manual systems, this movement or trace of the floating point would be connected to a series of mechanical arms that trace out the feature on paper. In digital photogrammetry, the tracing table is replaced by a computer that generates X and Y, Z coordinate arrays of the features. Coding is done to identify the traced features. The advantage of using this method to collect digital data is that elevation information is also recorded.

Existing digital sources are remote sensing images and data provided by Global Positioning Satellites (GPS). Reflected light or thermal radiation from features on the ground is measured and recorded by the sensors on board remote sensing satellites in

¹A. Bannister and S. Raymond, Surveying, fifth edition, (London: Pitman, 1984) p. 1 define surveying work as the art of making measurements of relative positions of features, natural and man made and the representation of this information graphically, numerically or digitally.

²The process of photogrammetry involves measuring images on photographs. A discussion of the principles and applications is in F. H. Moffit and E. M. Mikhail, Photogrammetry, third edition, (New York: Harper and Row, 1980)

the remote sensing process. Data is stored in form of pixels with the values corresponding to the intensity of radiation and transmitted to earth stations by microwaves. Positions in space are known precisely at any given time for the GPS. A receiver, placed over a point, on earth receives and records radio signals from the atomic clocks on board these satellites. The time taken for the radio signal to reach the receiver is recorded and converted, by a series of mathematical formulae, to X, Y and Z coordinates for the point whose position is required. Recordings from at least four satellites are necessary to produce readings of acceptable accuracy. Digital data from both GPS and remote sensing images can be entered into a GIS. Graphical data from computer aided design drawings can also be entered into a GIS by a direct file transfer.⁴⁴

Attribute data can be manually entered at the computer or may be read in from a data base or spreadsheet file. Municipal attribute data in the form of records is stored in manual registers or database files.⁴⁵ The data in manual registers can be entered into database files. These files can be then read into a GIS by use of pointers/indexes that relate this data to its graphic element in the GIS.

3.6 Data manipulation

Data received or incorporated into a GIS may not be suitable for the required applications. Data manipulation¹ is done to make this data suitable for analysis. This section will look at graphic and attribute data manipulation.

¹Oxford Dictionary defines manipulation as handling of objects for a certain purpose.

3.6.1 Graphic data manipulation

Graphic data entities entered in a GIS may have no intelligence. For instance data entered using a digitiser, is a series of lines, polygons or points whose positions are described by XY coordinates. To add intelligence to these features, a code is given to each entity to uniquely identify it.⁴⁶ The point of entry for attribute data for the entity is also identified and for polygons this is normally the centre of the polygon although other data management systems allow the entire object to be the point of entry.⁴⁷

Data received in the GIS may be on different coordinate systems than that of the real world. Geometric operations on both vector and raster (normally remotely sensed images) correct the data geometrically.⁴⁸ Geometric errors in raster type data caused by instruments, earth's curvature and rotation, and satellite motion are removed by use of mapping polynomials applied to the image. For vector type data, scaling, rotating and translation orients the digital map to real world coordinates. Registration then relates the geometrically corrected data to a coordinate system, for both vector and raster models.

Data collected may have unnecessary details. Data reduction and generalisation is performed to reduce the points in a line entity while still retaining its general shape in the vector data.⁴⁹ Resampling for raster type data, replaces a number of pixels by

⁴⁶Geometric operations are discussed in C. K. Clarke, Analytical and Computer cartography, (Englewood Cliffs, New Jersey: Prentice-Hall, 1990) ch. 9

⁴⁹Line reduction techniques are discussed in B. R. McMaster, "Automated Line Generalization," CARTOGRAPHICA, 24/2 (1987), pp. 74-111

one large pixel whose value is averaged from the others.⁴⁸ These processes reduce the amount of data stored in the computer for both data models.

Editing is carried out in digital data sets to remove errors that may have been introduced during digitising or scanning stages. Slivers or gaps produced from digitising polygon features need to be identified and removed. Editing in raster type data includes the removal of unwanted pixels that may have been a result of a stained map or in the case of images, cloud cover or radiometric factors.

Lines, points and polygons may be merged to create complex objects in the vector model.⁴⁹ For example, polygons are built from line features and dangling lines are snapped or clipped to the nearest point features.

Errors caused by paper shrinkage, different map production times, and digitising result in displaced features along the map screen edges. Edge matching is performed to align these features along the edges. This can be done physically by selecting the features and moving them or automatically by computing adjustment parameters from a series of points selected from adjoining maps. Conflation reconciles positions of similar features in different data layers.⁵⁰ For example, the frontage of a parcel, in the parcels layer, is conflated to match it with the street network in the streets layer.

Topological construction can be carried out to establish relationships between the entities.⁵¹ An example would be to identify what is to the right and left of a line segment, its starting node(point) and ending node, and the vertices(points) in between.

3.6.2 Attribute data manipulation

Attribute data needs to be modified to conform to particular applications. Data describing the condition of a street, for example, includes number of potholes, cleanliness, drainage ability, surface of the road, and date of last maintenance. This data can be classified into bad, good or average condition based on a selection criteria for each street. The general condition of a street is identified easily by the classification.

Spatial aggregation is done to attribute data to increase the size of the elemental unit in the database. For example census data may have been collected at the division level but the graphic data stored in the GIS is done at the district level. This data will need to be recomputed to conform to the resolution of the graphic data stored.⁵² Aggregating redefines the spatial unit at the district level to match with data collected at the provincial level.

3.7 Database management

Database management is the storage and organization of data to enable quick retrieval.⁵³ Data bases are organised along certain concepts depending on the use that is to be made of the data, the complexity of data models, the manipulations to be performed and the type of computer techniques used for manipulation and analysis.⁵⁴

Two considerations in database design relate to the physical database and the logical database.⁵⁵ The actual location of the data within the storage media is the physical database. The logical database is the user's concept of the relationships

between data sets stored on the computer.

Hierarchical, network, relational, and inverted are the basic data model concepts.⁵⁶ Information is stored in rows called records and columns called fields in the inverted data model. A record is a group of related items that are divided into fields. Keys or pointers are then provided for retrieving the records. Hierarchical data models are structured in the form of a tree with the root being the head of the tree representing the feature. Attributes of the features, in this model, are called parents and each parent can have further attributes called children. There can be no relationship between parents or children with this model and because of this restriction, the same data may be stored many times. The network data model provides relationships between the features and attributes. A parent can have multiple children and a child can have multiple parents. The drawback with this model is that the relationships are difficult to modify. Related data is stored in tuples in the relational data model. Tuples are grouped in two dimensional tables that are stored separately. The table is also known as a relation because it stores the relationship between the attributes.

Two variations of the above databases are the hybrid and integrated database. Graphic data is stored in files that can be directly accessed in the hybrid model. Attribute data is stored in standard commercial database files like dBASE IV. The GIS software then provides the link between the two databases by use of unique identifiers stored in both graphic and attribute data. Graphic data is stored in the same tables as the attribute data in the integrated data models. Object oriented database management

systems are an extension of the integrated model.

Regardless of a database model, it should be able to provide the following: a formal definition of the data that is whether the data to be entered is an integer, a date or a string; the fields that hold the information; and value restrictions on the data.⁵⁷ It should also be able to manage very large volumes of data in the order of giga and terabytes.⁵⁸ More requirements for databases and database designs are that they should:^o

- be able to answer two fundamental questions what is at a place? and are there examples of this object here?.
- be able to provide an efficient way of storing, retrieving, deleting and updating data.
- be capable of integrating data from different databases and be able to be accessed by many users.
- provide protection against accidental erasure, misuse and redundancy.

Some problems that have been identified with databases include the fact that the data stored in the database can only be used for certain functions and inconsistent data is often integrated into a database without paying attention to the resolution of the data and the data collection procedures.⁵⁹ Conventional database management systems do not completely address geographic applications because the data models, query languages and access methods were designed for simple data types like integers and strings.⁶⁰ Geometric operations required for graphic data are not fully supported by

^oThis list is adapted from J.Star and J. Estes, Geographic Information Systems. An Introduction, (Englewoods Cliffs, New Jersey: Prentice Hall, 1990)

current data base management systems, and geographic data is not suitably displayed.⁶¹ Although these problems are inherent in current databases, databases play a major role in GIS technology.

3.8 Spatial data analysis

Spatial analysis can be defined as the determination of patterns or relationships within features⁶² using logical or mathematical models for planning and decision making support.⁶³ The map on the screen is used as a querying tool in spatial query analysis.⁶⁴ The user points to a map feature and the computer comes up with a report of attributes of the pointed to feature on the screen. For instance, querying a manhole would provide information on the location, the type of manhole, the depth and the condition of the manhole. This data can also be changed and rectified as required. Data query is another spatial analysis function where by selecting the attribute data, the graphic image of data is displayed on the screen.⁶⁵ By use of filters, the class or type of data to be displayed is defined for the query.⁶ For instance, if a display of houses with three residents was required, a filter is created for this condition and the analysis function will display the buildings that have three residents.

Database integration option enable graphic data for points, lines and polygons to be linked to attribute data after geocoding.⁶⁶ Geocoding correlates an event or an activity to a spatial feature by use of a geographic identifier. This makes it possible to integrate data from different sources.

⁶The use of filters is demonstrated in chapter four of this thesis.

different sources.

Overlay operations involve the addition, subtraction, division and multiplication of data values between layers in order to create new variables.⁶⁷

Contiguous/nominal, non contiguous/nominal, contiguous/attribute, and non contiguous/attribute are forms of overlay functions.⁶⁸ In the contiguous/nominal overlay, features have the same physical shapes between the layers and nominal attribute values for the features. For example, a layer showing land use by parcel and another layer showing development by parcel can be overlaid to identify parcels that are developed according to the land use requirement. Layers may have the same physical shape and the attribute data can be manipulated mathematically or logically across the layers in the contiguous/attribute overlay. A building layer showing built space area and another of number of occupants can be overlaid and using the mathematical expression of area divided by occupants, create a variable that shows the square metres occupied by each person in the buildings for this form. Map graphic features vary in physical shape in the non contiguous/nominal overlay form but the attribute data is nominal. For instance, a flood area can be overlaid with a parcels layer to identify which parcels will be prone to flooding. The final form is the non contiguous/attribute overlay. In this form, graphic features vary in shape and the attribute data can be logically or mathematically manipulated across the layers. Overlaying a sewer network and a building layer can determine buildings connected to sewers that were 200 millimetre in diameter in this form.

In choropleth mapping, statistically generated values are used to shade or

the layers. Overlaying a sewer network and a building layer can determine buildings connected to sewers that were 200 millimetre in diameter in this form.

In choropleth mapping, statistically generated values are used to shade or colour features according to certain classification.⁶⁹ This function can be used in census mapping to show the population distribution in a certain area by polygons. The classes according to a set of defined set of rules are set and the computer shades polygons according to the value computed.

Thematic mapping and presentation refers to the coding and the selection of features based on common elements or classes and displaying this on a map.⁷⁰ The best example of thematic mapping is the land use map. The activities carried out on the land are classified into land use categories and then coded for each parcel. The analysis will display the result in form of a map with different shading patterns for each category.

Neighbourhood operations⁷¹ or proximity analysis⁷² enable the identification of features close to the selected feature. This can be looked at in terms of a distance between the features and the adjacency to a feature. Factors to be considered include, the target, the measure, the function, and the area to be analyzed.⁷³ For an overflowing sewer manhole, the target is the manhole, the measure is a radial distance of 100 metres, the function is to identify the parcels surrounding the manhole and the area to be analyzed are the parcels located within the identified radial distance of 100 metres.

Line in polygon and point in polygon functions define lines and point features

is a set of interconnecting lines that form a pattern or a framework. Water supply network, sewer network and street network are examples of networks. Routing and minimum path location,⁷⁶ network loading and resource allocation⁷⁷ are forms of network functions.

Routing and minimum path analysis identify the travel path of an object or resource from one point to another and selecting the shortest or optimal route from a set of alternative paths. The Police Department may like to know the fastest route to follow to a scene of a crime or emergency. The analysis process should be able to establish the optimal route by analyzing factors like the condition of the road, weather, speed limit and traffic.

Network loading involves the prediction of the substance passing a particular point. For instance, the water supply department may like to trace the path of harmful substances flowing through a certain valve and the speed at which these will flow.

Resource allocation refers to allocating sources to an area that could be reached in equal time. Jurisdiction of a police station depending on the time taken to reach a destination is defined thus.

Four factors to be considered in network analysis are the resources, the location, objective and constraints.⁷⁸ For instance, with the police station example, the resource would be the police protection or intervention, the location would be the police station, the objective would be to deliver the services or to be at a crime as soon as possible and constraints the condition of the road, the speed limit time, and traffic control.

Spread analyses evaluate the time and cost taken for the coverage of a certain activity.⁷⁹ These functions evaluate activities that accumulate with distance. The spread of a fire, or the spread of an oil spill can be evaluated with these analyses. In the example of an oil spill, modelling of the nature of spreading of oil over a water surface are built into the analysis and for a certain time the spread is shown and recorded. Barriers to the flow of this oil can be traced by using stream and seek functions.

View shade modelling or view shade mapping functions are used to locate areas that can also be seen from a specified place.⁸⁰ In this case digital elevation data is used to define the topography of the terrain. Perspective view and illumination capabilities provide a visual aspect to terrain analysis.⁸¹

Cartographic or GIS modelling is the use of analysis functions to solve complex spatial problems.⁸² A combination of the above analysis capabilities is incorporated towards solving a complex spatial problem. The location of a possible land fill site for the Greater Toronto area was identified by modelling.⁸³ Many factors had to be considered and included information on agriculture, drainage patterns, traffic both air and ground, socio-economic factors and environmental issues.

3.9 Data output

Data output is the process of disseminating information to the user in a form that is suitable and understandable. Output products include hard copy, soft copy and electronic.⁸⁴ Hard copy refers to maps, table, charts and graphs produced on paper

products and soft copy refers to output as viewed on the screen. Soft copy products can be interactive or animated.⁶⁵ Interactive maps displayed on the screen can be changed by the user while animated maps change continually in shape and content on the screen. Electronic output is in the form of computer compatible file format. Data output can also be divided into map and non map products.⁶⁶ Non map products are in form of bar charts, pie charts, scatter plots, histograms, and data extracted from the entities. Thematic maps, land form maps, dot distribution maps and contour maps are types of map products. The hardware devices for producing hard copy maps include pen plotters, line printers, dot matrix printers, thermal plotters and optical film makers.⁶⁷ The Cathode Ray Tube is employed in the soft copy output. An electronic gun is set to bombard the screen or tube coated with phosphorous that glows according to how the electrons are shot towards the screen. A coloured screen will have three guns: red, blue, and green to produce features on the screen in colour.

3.10 Critique of GIS technology

GIS is an important tool for use in mapping, database management and data analysis functions, but it is not without its shortcomings. Three major areas of shortcoming for the technology have been identified and are economic, institutional and technological issues.⁶⁸

3.10.1 Economic issues

The measurement of economics is normally based on the benefits to be accrued

from installing a GIS and this is often difficult to evaluate. These are based on labour and time saving costs in operations done manually, benefits of providing new services and new target markets, and better decision making.⁸⁹ Long periods of time will have to pass before the technology benefits are realised. The task will be in convincing the policy makers to set up an expensive system whose benefits will not be realised immediately.

The cost of hardware and software is prohibitive especially for developing countries but the falling costs will make the technology more affordable by the developing nations. On the other hand, by the time the project is implemented, the hardware and software is out of date and will require to be updated.⁹⁰ The building of data bases take a long time and requires a lot of money. Good data base design will help keep the cost to a minimum. It is estimated that 75% of the cost of implementation is spent on data base creation⁹¹ although it has been argued that the cost of training people can outstrip the total cost of hardware, software, and database development.⁹²

3.10.2 Institutional issues

GIS transmit data directly from the events to the management. Lower and middle management officials have little control over this and as a result, loss of control and authority over some aspects of management.⁹³ GIS training is normally focused on the operators but the people in the environment within which it will be installed, also need to be trained in order to appreciate the capabilities of the

system.⁹⁴

Although the technology has developed rapidly within the last two decades, institutional and political changes within organisations have been slow.⁹⁵ Agencies that are charged with collecting data perceive the data as belonging to them and are unwilling to share this with other agencies. Since departments that used to work alone will be forced to work together, issues of data standardisation, legal liabilities and protection of individual privacy will need to be addressed.⁹⁶

People view information from computer products to be error free and accurate and the people who prepare this data should be responsible for its accuracy and integrity. The importance of data quality and accuracy requires that it be addressed in detail. Chapter 5 of this thesis looks at factors affecting data quality and accuracy within a GIS environment.

3.10.3 Technological issues

GIS technology is focusing more on how data is organised and analyzed than on digital data collection strategies. The present digital data collection methods of scanning and digitising require a lot of time and by the time data is fully integrated in the system, the data is out of date. Attempts are being made to improve things with the introduction of artificial intelligence in data conversion procedures but the results have been unsatisfactory.⁹⁷ The technology is being pushed by vendors as being able to perform certain tasks but ignores the fundamental issues of organization and understanding of the technology in the environment where it is being set up.⁹⁸ Spatial

analysis techniques in current GIS are restrictive because the spatial models and object relationships are difficult to define.⁹⁹ Contributions from cartographers, psychologists and visual artists will aid in identifying media and perception of space.¹⁰⁰

Most GIS are fixed in time in that the period of data entry is noted but subsequent updates to the data are not recorded.¹⁰¹ It is therefore difficult, for example, to trace the history of a subdivision within a GIS as compared to the manual record systems. Technical terms used by the people within the GIS sphere tend to scare off potential users. Since GIS being developed by different agencies, data exchange is difficult because of the different data collection and processing standards.

GIS can perform an array of spatial analysis and database operations but this increases the software complexity and the difficulty to use. Software is not user friendly although PC based Windows type GIS are appearing on the market. Software development for GIS, is geared towards certain applications and this makes it difficult to use it for other applications. For instance, systems developed to study the potential for developing an area for agricultural use by analyzing the carrying capacity of the land, the soil type and probably the rainfall patterns are specific to this purpose. An application like studying the settlements within this area may require that another system be designed to address this problem. There is a need to develop GIS that are general and for which users can select components to suit their own applications although this adds to the complexity of the software.

Despite all the shortcomings and problems of the application of GIS technology, the proper implementation can aid in the analysis of geographically related

data. The most important thing is that the developers and users of the system are aware of the capabilities and also the limitations of the technology.

3.11 GIS in urban infrastructure management

The Engineering Division in the Public Works Department, of the City of Nepean in the Regional Municipality of Ottawa Carleton (RMOC), has developed Infrastructure Management System (IMS) that stores records of attribute data on infrastructure in an ORACLE database system.¹⁰² The graphic information used is from the National Capital Commission digital maps at scale 1:2000 for the area. GIS will be used to link the graphical data to the textual database. The software used is VISION, a CAD based software, operating on a local area network (LAN) on a SUN UNIX station. At present, a pilot project is being developed to justify IMS as a GIS application for the whole City of Nepean. Applications to be developed for this GIS will include: identifying sewer carrying capacity, modelling sewer pipes and updating, and producing road maintenance maps. Services to residents calling to enquire about services is also expected to improve with the easy access to data.

The Environmental Services Department in the RMOC is also currently developing a GIS to store data on services offered to its citizens.¹⁰³ The GIS software used is GEOVISION. The department's duties include the management of: treatment works, solid waste disposal sites, collector sewer system, water supply, and environmental services. The project began in March 1992 and is expected to be completed by the end of summer of 1994. Data kept on the Region include street

centre line data, water network data, an inventory catalogue for the water pipe attributes, and digital base maps at scale 1:2000 from the National Capital Commission. The water network data was digitised and given pipe identifiers and valve identifiers that enabled the water network to be linked to the street address database. At present there are about 75,000 records that are handled by the GIS.

GIS application to urban management in developing countries has been proceeding at a very slow rate. In addition to the problems addressed earlier with GIS, the following have been singled out as crucial to the establishment of GIS in developing countries:⁴

- lack of funds to set up and maintain an overall GIS within a municipality.
- lack of good quality data both in digital and non digital form.
- poor data collection techniques.
- lack of effective institution management within the urban authorities and also across the departments charged with managing the urban areas.
- the potential of GIS as a planning tool has not been appreciated both by the planners and the policy makers.
- current software that is introduced in these countries is not easily understood and does not address problems that are unique to the area.
- shortage of qualified people that understand the potentials and capabilities of this technology.

⁴The list of factors affecting development of GIS in developing countries especially in urban areas are adopted from A. G. Yeh, "The development and applications of geographic information systems for urban and regional planning in the developing countries", and D. A. Hastings and D. M. Clark, "GIS in Africa: problems, challenges and opportunities for co-operation" in International Journal for Geographical Information Systems, vol 5, no. 1 (Jan - March, 1991) pp. 5-27, 29-39

- education and training facilities for GIS in developing countries have not been fully developed.
- departments that tend to benefit from GIS are not coordinated and already have organisational problems that will need to be addressed.
- data for the creation of a database comes from different departments and agencies. Since each department collects its own data, rules and specifications may not be compatible with data from other departments.
- GIS may be thought of as a process that will replace menial tasks of drafting and data input. Many departments may be reluctant to adopt this technology because of the fact that it may lead to the elimination of certain job categories.

The capability of GIS to store, manipulate and analyze large volumes of data in an efficient way may place a lot of data in the hands of a few people and policy makers realising this, may be willing to adopt GIS technology. The danger is that the policy makers, having more control of data, may use this to pursue their own goals by suppressing or altering information to suit their purposes. This is not to say that they can not do so otherwise, but that the efficient data handling and analysis capabilities make information available to the policy makers almost immediately.

This thesis looks at the application of GIS to urban management using a multipurpose approach. This approach involves developing a system that will be useful for urban planning within a municipality. An argument is made for the establishment of GIS outside the traditional departments as a separate department that integrates data from the other departments. Requirements for, and applications of, GIS are discussed by a team of personnel drawn from each department in the multi purpose model. Problems and data requirements for each sector are discussed and a standard way of collecting data is established.

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CHAPTER FOUR

PILOT STUDY

4.1 Objective

The objective of this pilot study is to investigate the suitability of Geographic Information Systems technology to managing urban infrastructure data for an urban area in a developing country. TIMS, a CAD based GIS software, will be used to demonstrate this on a section of the Province of Nairobi, Kenya.

4.2 The study area

The area chosen is approximately located at the centre of the Province of Nairobi, Kenya (Fig. 3). The average altitude of this area is about 1600 meters above sea level. The study area covers approximately 14 square kilometres. It is considered a prime area because of its location with respect to major communication routes (Fig. 4). It also traverses several administration boundaries. Furthermore, the area is developing rapidly economically and zoning regulations are continuously changing to cope with the growth.

4.3 Sources of data

Streets, parcels(lots), railway lines and rivers within the study area were digitised from an enlarged copy the base map City of Nairobi, Map and Guide, Scale

Figure 3. The Study Area

Figure 4. Major highways

NAIROBI: MAJOR HIGHWAYS

Map sources: Survey of Kenya
Nairobi Parliamentary Constituencies
City of Nairobi Map and Guide

SCALE 1 : 250 000

Produced by TMS
Geographic Information Systems Division
Energy, Mines and Resources

701:20,000 with the Universal Transverse Mercator (UTM) coordinate system. The base map used to digitize the location of the study area with respect to the rest of Nairobi was Nairobi Parliamentary constituencies sheet A published by Survey of Kenya in 1991. The scale of this map was 1:50,000. The entire water supply map for the whole province was digitised from a copy of a map supplied by City Council of Nairobi, Water and Sewerage Department prepared in 1989 and is shown in figure 5. The sewer network, shown in figure 6, for the whole province was digitised from a copy of the Master Plan for Sewerage prepared in August 1974 for the City Council of Nairobi. Major highways (figure 4) were digitised from the City of Nairobi Map and Guide and from Nairobi Parliamentary constituencies, sheet A.

The following graphic entities within the study area were improvised as data were not available: sewer and water pipe networks, sewer and water manholes, water valves, noise buffer and road expansion zones. Streets and parcels were digitised from copies of City of Nairobi, Map and Guide scale 1:20,000. Most of the attribute data for the above graphic entities within the study area were improvised because they were not available. This is explained in detail later on in the chapter.

4.4 Description of software used

This section describes the software used for this pilot study. Four software packages were used: AutoCAD Release 12, PC ARC/INFO, Total Information Management System (TIMS) version 12 and dBASE IV. ARC/INFO and AutoCAD software were used to digitise graphic entities. Non graphic entities or attributes were

Figure 5. Main water supply

Figure 6. Main Sewers

stored in file structure of dBASE IV. TMS, a user friendly GIS software that runs completely within AutoCAD, was used to create the link between the graphic and attribute entities.

4.4.1 AutoCAD software^a

AutoCAD is a computer aided design and drafting application software. Line, circle or a text string are the basic entities provided in AutoCAD for the drawing functions. An AutoCAD drawing also acts as a database containing precise locations, sizes, colours and attributes of the objects drawn. Table 4 lists entities that can be drawn in AutoCAD:^b

Table 4. Entities created in AutoCAD

<u>Variable</u>	<u>Comments</u>
Line segments	drawn with a mouse or by entering coordinates at the keyboard or relative distance at the keyboard.
Polylines	drawn as two dimensional or three dimensional lines.
Arcs	drawn by defining three parameters. The options are: the start, the centre, end; start, centre and included angle; start, centre and length of chord; start, end and radius; start, end and included angle; and start, end and starting direction.

^aFor a complete description of AutoCAD, see Autodesk Incorporated, AutoCAD Reference Manual, (Sausalito, California: Autodesk Inc., Aug 1992)

^bThis list is not exhaustive of the entities that can be created with AutoCAD. For a full description of drawing entities possible within AutoCAD, see Autodesk Incorporated, AutoCAD Reference Manual, (Sausalito, California: Autodesk Inc., Aug 1992)

Polygons	drawn by defining the radius and the number of sides. The smallest polygon can have 3 sides and the largest, 1024 sides.
Inserts	a collection of entities saved together as a block that can be inserted into any drawing file.
Trace	a line drawn of a defined width.
Points	drawn for defining entities that are of one dimension.
Text	entered at the key board interactively or read in from a text file. Options include changing the font, colour, style, justification.

Options provided to aid in drawing entities include the ability to snap entities to intersecting lines, to end points, to centres of or tangent to circles. A grid is also provided to aid in alignment of features. Zooming enables small features to be seen. Drawings from other software can be imported into AutoCAD as DXF files.

AutoCAD contains powerful editing functions. Entities can be erased, copied, divided, moved, rotated, and measured. Properties of entities like colour, text, size, layer and line type can also be modified. Drawing limits are set that define the extent of the drawing in the required units that include scientific, decimal, engineering, architectural, and fractional drawing units. Angle measurements supported in AutoCAD include decimal degrees, gradients, radians, degrees minutes and seconds, and surveyor's type.

Within each AutoCAD drawing file, layers are created to contain a set of related entities. Layers are turned on as required so that the entities drawn are stored on the active layer known as the current layer. When a layer is locked, entities are displayed

but not edited. Entities are not displayed when a layer is turned off or frozen. Drawings from other software can be imported into AutoCAD as DXF files. Plotting functions in AutoCAD provide the ability to plot to a postscript file. A plot can also be rotated, scaled and previewed before it is finally produced as hard copy.

4.4.2 ARC/INFO*

The ARC Digitising System (ADS) module in ARC/INFO software was used to digitise graphic entities. Related graphic entities are stored in a data layer called a coverage. Entities supported in ARC/INFO are arcs, nodes, vertices and tics. Arcs can be line features or polygon borders and are defined by two end nodes and vertices in between the nodes. Tics are registration points with known geographic coordinates that are used for orienting the map coordinate system to the digitiser coordinate system. After digitising, the coverage is examined to ensure that arcs snap onto nodes. The command CLEAN is applied to the coverage to achieve this. ARC/INFO coverage can be converted to DXF files and exported to other drawing software like AutoCAD. The arcs become polylines, the nodes become points and a coverage is stored on a layer within the AutoCAD environment.

*More details on using ARC/INFO software can be found in Environmental Systems Research Institute (ESRI) Incorporated, Understanding GIS. The ARC/INFO method, (Redlands, California: ESRI Inc., April 1990).

4.4.3 dBASE IV^d

This software was used to create the data structures for attribute data and to store these data in the structures. The structure of the data to be entered is defined by choosing a field name and specifying the field type. Character, numeric, float, date, logical and memo are the field types supported by dBASE IV. For each field, the width of its data is determined, for example if the field was NAME, the field type would be character and the field width 15. For numeric and float type data, decimal places are defined.

4.4.4 TIMS software^e

TIMS, is a user friendly GIS software that runs completely within the AutoCAD environment. This allows access to the powerful editing and drawing functions of AutoCAD software. Object oriented technology is used to link graphic entities in AutoCAD to attribute data stored in data base files like dBASE IV, ORACLE and to spreadsheets like Lotus. The analysis functions provided are suitable for addressing urban infrastructure management problems as will be demonstrated later on in this chapter. TIMS software runs on DOS 386 and 486 personal computers and on a

^dA description of the software and its applications can be found in Ashton-Tate Corporation, Using the Menu System, (Torrance, California: Ashton-Tate Corporation, 1988,1990)

^eFor more explanation on TIMS software see Object Graphics Incorporated, TIMS R12 Total Information Management System. User's Guide, (California: Object Graphics Inc., 1992,93)

network, on the Sun Sparc and IBM RS6000 platforms.

Information in TIMS is structured in a hierarchical manner (figure 7). For instance, a project is defined to contain graphic images representing the different components that are entities created within the project. Entities supported in TIMS include 3DFace, Arc, circle, insert, pline(polyline), point, shape, solid and text. For each component, a set of variables describing or qualifying the entity are created. Variables supported by TIMS are listed in table 5 below.

Figure 7. TIMS structure

Table 5. Variable in TIMS

<u>Variable</u>	<u>Description and options</u>
Internal variable	created and stored in the extended portion of each AutoCAD entity. Sub types can be a date from year 1000 to 9999, an integer from -32,768 to 32,767, a long integer -2147483648 to 2147483647, a real number from 1.0e-30 to 1.0e+30 and for strings up to 31 characters.

External variable	created to link graphic entities to an external file including LOTUS, dBASE, ASCII or ORACLE files and subtypes of this variable include date, real, integer, long integer and string with the same range as internal variables.
Computed variable	created to store results from adding, subtracting, multiplying, dividing and concatenated strings of other variable values.
Duplicate variable	created to store temporary copies of data linked by external variables and also to change the variable type from string to integer or integer to string.
Link variable	created to link a graphic entity with an image or a hypertext file. Image files supported are PCX and AutoCAD slide files.
Network variable	created for segments or sections of networks to store the direction of flow for each segment.
Statistical variable	created to provide statistics on average, total and count of the surrounded entities within a surrounding entity.
Relational variable	created to enable two components to be linked together in five different ways: englobing pline that links an entity to the surrounded entities; multiple that links one entity to many entities; nearest and specific types that link entities to the nearest and specific entity; and the last type links objects inside an entity to the surrounding entity.

TIMS analysis functions include the following^f:

(i) **Proximity analysis** performed on a component locates other components within a defined distance. This analysis was used to determine the parcels that were within a radius of 120 metres of an overflowing sewer manhole.

(ii) **Network analysis** locates nodes at the end and at a connection of a network. This analysis was done for the water pipes network to locate buildings at the end of the

^fA detailed account of TIMS analysis functions are discussed later in the chapter.

network and water meters located along the water pipe network.

(iii) Thematic analysis is used to emphasize a selection of entities by giving them different colours. The land use map by parcels was prepared with this analysis.

(iv) Statistical analysis is used to display data as a pie chart or a bar graph. The percentage tax collected by block was presented by a pie chart and the tax collected by parcels bar graph was prepared with this analysis.

(v) Polygon overlay function creates an intersection from two polygon layers. This function was used to show parcels that would be affected by road expansion. Buildings located within the noise buffer were also identified with this function.

(vi) TIMS integrates data from different sources like data base files, LOTUS spread sheets, ORACLE and ASCII file formats. Data from two database files, lots.dbf and building.dbf, were integrated for the same component, BUILDING. Scanned PCX formatted imagery can also be linked to entities within TIMS. Scanned images of buildings were attached to building entities.

(vii) TIMS is able to manipulate digital geographic data by building polygons from line segments or polylines. This was done for the PARCELS and STATSBLOCKS layer to construct polygons from polylines. Overshoots and undershoots can also be eliminated, and transformation of data from one set of a coordinate system to another is possible.

(viii) Spatial queries are also done within TIMS. In spatial queries, the graphic display is used to access the database. TIMS is able to produce reports for a selected set of entities. By incorporating filters, reports showing selected entities based on a

defined query can be produced. This was done to select buildings whose value lay between 700,000(C\$14,000) and 1,000,000(C\$20,000) Kenya shillings.

(ix) Data query that involves querying the database, is also supported by TIMS software. This function was used to show sets of entities that had previously been selected and saved. For instance, the set containing water pipes constructed before January 1950 was displayed and flashed on the screen. The variable LOT_NO of the component PARCELS was sorted and a data query was also performed on the sorted list by selecting a particular LOT_NO value.

(x) Data on graphic entities can be extracted to database files, comma delineated files(CDF), and to space delineated files (SPF). Data describing the location of point entities, length of line entities and areas of polygon entities were extracted by this option.

(xi) The Report Generator utility in TIMS enables reports on entities to be produced. This function was used to produce reports for the analysis performed on data.

4.5 Data input

Data input refers to geocoding of the data, and preparation of data and maps for introduction to the computer. This section deals with both graphic and attribute data input. A summary of the graphic data layers involved in the study is also presented. A detailed description of data input and manipulation is done for each data layer. Graphic data input for streets and parcels was done in the ADS module of ARC/INFO. Data input for some graphic entities like water valves, manholes and bridges was done in

AutoCAD software.

Attribute data input was done using both dBASE IV and TIMS software. Data fields were created in dBASE IV with at least one of the fields having the same characteristics as the internal variable created within TIMS for similar entities. Data input using TIMS software will be described in detail.

4.5.1 Summary of graphic data layers

This section summarises the graphic data layers that were created both in AutoCAD and TIMS software. A data layer stores graphic information on features of the same class or type. Table 6 lists layers created for data produced from TIMS analysis functions.

Table 6. AutoCAD layers created by TIMS

<u>Layer</u>	<u>Entity</u>	<u>Description</u>
ANNUALTAX_BARGRAPH	Graph	Bar graph of annual tax collected by parcels.
BLOCKTAX_PIECHART	Chart	Pie chart of tax collected by city block.
BUILDINGINBUFFER	Polyline	Overlay of building footprints and noise buffer zone
LANDUSE_PATERN	Polyline	Land use thematic map by parcels.
ROADWIDE_PARCEL	Polyline	Intersection created by overlaying Road widening buffer and lots(parcel).
SHORTESTROUTE_BARGRAPH	Polyline	Bar graphs showing shortest time to

travel from place A to place B.

Table 7 lists layers for data created using the powerful drawing functions in AutoCAD. Detailed description is given later for each layer.

Table 7. Data layers created in AutoCAD

<u>Layers</u>	<u>Entity</u>	<u>Description</u>
BRIDGES	Insert	Location of bridges.
BUILDINGS	Polyline	Footprints of buildings.
FIXED_LOTS	Polyline	Input of lots from survey plans.
METERS	Insert	Location of water meters on water pipe network.
NOISECONTROLBUFFER	Polyline	Noise control buffer zone.
ROUTEALLOCATION	Polyline	Possible routes between place A and B.
INTERSECTIONS	Circle	Major road intersections.
NOISECONTROLBUFFER	Polyline	Noise control buffer zone.
ROADWIDENING	Polyline	Proposed road expansion buffer.
ROUTEALLOCATION	Polyline	Possible routes between place A and B.
SEWERMANHOLES	Inserts	Manholes for sewer network in study area.
SEWERS	Lines	Sewer network in study area.
STATBLOCKS	Polyline	City blocks enclosing lots(parcel).

2

PM-1 3½"x4" PHOTOGRAPHIC MICROCOPY TARGET
NBS 1010a ANSI/ISO #2 EQUIVALENT

PRECISIONSM RESOLUTION TARGETS

VALVES	Insert	Location of valves on the water pipe network.
WATERMANHOLES	Insert	Location of water pipe manholes.
WATERPIPES	Lines	Water pipe network of study area.
HIGHWAYS	Polyline	Major highways traversing the study area and the province of Nairobi.
RIVERLINES	Polyline	Major rivers flowing through province of Nairobi.
RAILWAYLINE	Polyline	Major railways through province of Nairobi.
SEWAGEWORKS	Polyline	Major sewage layout and sewage works for Nairobi province.
STUDYAREA	Polyline	Location of study area within the province of Nairobi.
WATERWORKS	Polyline	Major water supply network for the province of Nairobi.

Layers with data that was digitised using the ADS module of ARC/INFO and imported into TIM/AutoCAD environment as DXF files are shown in table 8.

Table 8. Data layers imported from ARC/INFO

<u>Layer</u>	<u>Entity</u>	<u>Description</u>
CONSTITUENCIES	Polyline	Constituencies of province of Nairobi.
LOCATIONS	Polyline	Locations within constituency of study area.
SUBLOCATIONS	Polyline	Sublocations of locations within.

		study area.
NAIROBI	Polyline	Boundary of province of Nairobi.
PARCELS	Polyline	Parcels (lots) within study area.
RAILWAY	Polyline	Railway through the study area.
STREETS	Polyline	Streets in study area. The streets were redigitised in AutoCAD as single lines.
RIVERS	Polyline	Rivers flowing through the study area.

Layers created to contain textual information and plotting frames for the purpose of data display and output are shown in table 9.

Table 9. Data layers for display and output

<u>Layer</u>	<u>Entity</u>	<u>Description</u>
BUILDINGS_TXT	Text	Building identifying numbers.
CONSTITUENCY_TEXT	Text	Names of constituencies.
HIGHWAYS_TEXT	Text	Title of highway plot.
LOCATIONS_TEXT	Text	Names of locations and title of location plot.
LOT_TXT	Text	Unique parcel identifiers.
NAIROBI_FRAME	Frame	Map frame and text for plotting.
NAIROBI_TEXT	Text	Title of plot for Province of Nairobi.
PARTOFSTUDYAREA_FRAME	Frame	Frame for plotting within study area.

RAILWAYLINE_TEXT	Text	Title of major railway plot.
RIVERLINE_TEXT	Text	Title of major rivers plot.
STATBLOCK_TEXT	Text	Names of City blocks.
STREETNAMES	Text	Street names.
STUDYAREA_FRAME	Frame	Plotting frame for study area plots.
SUBLOCATIONS_TEXT	Text	Names of sublocations and title of plot.

The following layer was created to store changes in parcel subdivisions that had occurred since 1970. This is depicted in figure 8. AutoCAD digitising software was used to digitise these changes.

<u>layer</u>	<u>entity</u>	<u>description</u>
CHANGE	Polyline	New lot subdivisions since 1970.

4.5.2 Description of data input and manipulation

This section describes in detail data input and data manipulation for the data layers listed above. The layers are classified into functions of the urban administration and include Transport utilities, Land Management, Sanitary services and Buildings.

4.5.2.1 Transport utilities

Transport utilities described below include streets, intersections and bridges. These have been selected as an example of data associated with transport utilities and may not completely exhaust all the possible entities.

NEW SUBDIVISIONS SINCE 1978

Figure 8. New subdivisions since 1978

Streets

This layer represents the single street line network. Double street lines were first digitised in ARC/INFO as arcs. After CLEANING, the arcs were exported in a DXF file and imported into AutoCAD/TIMS. The single street line network was then digitised between the double street lines. Each section of the street between two intersections was treated as a polyline.

A component, STREETS was formed of entity type polyline. A unique street identity was given to each main road, for example, Ngong Road was given the identity 0005. The different sections along Ngong Road then were identified as 0005_001, 0005_002 etc. This unique identity was attached to each road section by the command 'attach data and increment counter' in the TIMS. Variables created for this component are listed in table 10.

Table 10. Variables for STREETS component

<u>Variable</u>	<u>Description</u>
CONDITION	an external variable created to read values that specify the condition of the streets: good, bad or average.
DATE_PAINTED	an external variable created to read values for the last date the street was painted.
LENGTH	an external variable created to read values for the length of the street section in metres. These values were initially extracted as graphic attributes for the streets.
NAME	an external variable created to read values for the street names.
NO_ OF_LANES	an external variable created to read values for the number of lanes in the street.

ROADCOST	a variable whose values were computed by the expression $\text{LENGTH} \times 15000$ for the cost of construction of the street section. The value 15000 is a constant that could be determined by considering the cost per metre in the construction of the road.
TYPE	an external variable created to read values for the type of street: lane, street, avenue, close, rise, crescent or highway.
ZEBRASX	an external variable created to read values for pedestrian crossings within the street section.
DIRECTION	an external variable created to read values for the flow of traffic as a network entity.

Attribute data for this layer were stored in the data base file, streets.dbf. Table 11 below shows the complete file structure for this data base file. This file contained 146 records.

Table 11. File structure for streets.dbf

Field	Type	Width	Decimal	Comments
Condition	character	10	-	street condition
Date_paint	character	10	-	paint date
Direction	character	10	-	flow of traffic
Name	character	10	-	street name
No_of_lane	character	10	-	street lanes
Str_no	character	10	-	street identity
Type	character	10	-	type of street
Zebrazx	numeric	10	0	pedestrian crossing
Rd_length	numeric	10	2	length of street section

Bridges

This layer represents the location of bridges within the study area. The layer **BRIDGE** was formed and made current. The layers **STREET**, **RIVERS**, **RAILWAY** were turned on but locked. A bridge symbol was constructed and saved as a block, **BRIDGE**, in AutoCAD. The block, **BRIDGE**, was then inserted at the appropriate locations on the street network.

A component, **BRIDGES**, was created with entity feature type insert. An internal integer type variable, **BRID_NO** was formed under this component. Internal variable values were attached to the bridges using the command 'attach data and increment counter' in the 'data linkage' menu in TIMS. External variables created under this component are shown in table below 12.

Table 12. Variables created for BRIDGES component

<u>Variable</u>	<u>Description</u>
BRIDFINISH	an external variable created to read values for date of completion of the bridge.
BRIDLENGTH	an external variable created to read values for length of the bridge.
DRYHEIGHT	an external variable created to read values for the average invert distance between bridge and the feature the bridge crosses during the dry season.
WETHEIGHT	an external variable created to read values for the average invert distance between bridge and the feature the bridge crosses during the rainy season.
FEA_CROSS	an external variable created to read values for the description of the feature that the bridge crosses.

- FEA_ONBRID** an external variable created to read values for the description of the feature on same grade level as bridge.
- Z_COORD** an external variable created to read values for the height of the centre of the bridge above sea level.
- CLEARANCE** a variable whose values were computed by the expression **DRYHEIGHT - WETHEIGHT** to show the difference in the level of the water in the dry and wet season.
- X_COORD** an external variable created to read values for the X coordinate. These values were initially extracted as graphic attributes.
- Y_COORD** an external variable created to read values for the Y coordinate. These values was initially extracted as a graphic attribute.

Attribute data for these variables were read in from the data base file, bridge.dbf. The structure of this file is shown in table 13. There were 10 records in this file.

Table 13. File structure for bridge.dbf

Field	type	width	Decimal	Comments
Brid_no	numeric	2	0	bridge identity
Type	character	10	-	bridge type
Dryheight	numeric	4	1	height in dry season
Wetheight	numeric	4	1	height in wet season
Fea_cross	character	15	-	feature crossed
Fea_onbrid	character	15	-	feature on bridge
Bridfinish	date	8	-	date bridge completed
Bridmain	date	8	-	date bridge checked
Bridlength	numeric	4	1	length of bridge
x_coord	numeric	11	2	x coordinate
y_coord	numeric	11	2	y coordinate

Intersections

This layer represents data on major road intersections in the area. The STREET layer was turned on but locked. An intersection symbol of two concentric circles of sizes 27m and 10m, within the scale, was created and copied to the appropriate road intersections using the 'copy' command in AutoCAD submenu.

A component called INTERSECTIONS was created of entity type circle. A layer INTERSECTION_TEXT was formed to contain the unique identification of intersections by integers. An internal string variable, INT_NO was created. Internal variable data of the form INT_? where ? is replaced by the integer identifying an intersection, were attached to the outer circle of the intersection symbol using the command 'attach data and increment counter' in the 'data linkage' submenu of TMS. Table 14 shows external variables created for this component.

Table 14. Variables created for INTERSECTIONS component

<u>Variable</u>	<u>Description</u>
DATE_MAIN	an external variable created to read values for the last date that traffic lights were maintained.
INT_FEATURE	an external variable created to read values for the feature at intersection i.e. a traffic island, a roundabout, none.
LIGHT_TYPE	an external variable created to read values for the type of traffic light.
NO_OF_ROADS	an external variable created to read values for the number of street segments meeting at the intersection.
NO_OF_RTAS	an external variable created to read values for the number of road traffic accidents occurring within a certain period.

OFF_CAR_RATE	an external variable created to read values for the rate of traffic flow of vehicles during the off peak hours per minute
OFF_PEDES_RATE	an external variable created to read values for the rate of flow of pedestrians during off peak hours per minute
ON_CAR_RATE	an external variable created to read values for the rate of flow of traffic during the rush hours
ON_PEDEST_RATE	an external variable created to read values for the rate of flow of pedestrian traffic during the rush hours.
STREETS_MEETING	an external variable created to read values for the names of streets that meet at the intersection
X_COORD	an external variable created to read values for the geographic location of the centre of an intersection. These values were initially extracted as graphic attributes.
Y_COORD	an external variable created to read values for the geographic location of the centre of an intersection. These values were initially extracted as graphic attributes.

Attribute data for this layer were stored in the database file, `intsect.dbf`. All the above variables had data except for variables `NO_OF_RTAS`, `OFF_CAR_RATE`, `OFF_PEDEST_RATE`, `ON_CAR_RATE`, `ON_PEDEST_RATE` and `STREETS_MEETING`. The data structure for `intsect.dbf` is displayed in table 15. A total of 17 records were stored in this file.

Table 15. File structure for intsect.dbf

Field	Type	Width	Decimal	Comments
Int_no	character	10	-	intersection identity
Gr_x	numeric	10	2	x coordinate
Gr_y	numeric	10	2	y coordinate
No_of_road	numeric	2	0	streets meeting
Light_type	character	6	-	traffic light type
Streetnames	character	30	-	name of street
Ofpe_ca_ra	numeric	6	0	data not included
Onpe_ca_ra	numeric	6	0	data not included
Onpe_pe_ra	numeric	6	0	data not included
Int_feat	character	8	0	intersection feature
No_of_rta	numeric	8	-	data not included
Date_main	date	8	-	date traffic light checked

Roadwidening

This layer was created to store graphic data to show a road widening buffer along major roads. The purpose of this was to highlight the areas required for road expansion. The location of this buffer was digitised by the 'draw' command in AutoCAD. This was an arbitrary location of this buffer. Factors including the volume of road, future development plans, and zoning controls can be used to determine the size and location of the buffer in real situations. The ROADWIDENING layer was made current and the PARCELS layer was turned on but locked.

A component, ROADWIDENING, was created of polyline entity feature. An

internal string variable ROADWIDBUFFER was created and attached to the different buffer zones using the option 'attach data to one entity' in the 'data linkage' submenu of TMS. No attribute data were stored for this component.

Routeallocator

This layer represents graphic data on possible routes between two places, A and B. The layer PARCELS was turned on but locked and the layer ROUTEALLOCATOR was made the current layer. The different possible routes were digitised as polylines in four different colours.

A component, ROUTEALLOCATOR, was created with polyline as its entity feature. An internal string variable ROUTE_NO was created and linked to each of the four routes using the command 'attach and increment counter' in the 'data linkage' submenu of TMS menu. The internal variable was of the form ROUTE_? with ? being an integer identifying each route. Variables created for this component are shown in table 16.

Table 16. Variables for ROUTEALLOCATOR component

<u>Variable</u>	<u>Description</u>
DESCRIPTION	an external variable created to read values that describe the route to be followed.
DISTANCE	an external variable created to read values for the total distance of the route.
NORMALTIME	a variable created whose values were used to compute values for the variable TOTALTIME described below. NORMALTIME

was computed by the expression $DISTANCE/5000$. The value 5000 is a constant that can be determined by considering factors like speed limit and road conditions

- TOTALTIME** a variable whose values were computed from by expression $NORMALTIME \times 60$ for the time taken to travel in ideal traffic conditions. The value 60 is used to convert from hours to minutes.
- OFFTIME** a variable whose values were computed by the expression $OFFFACTOR \times 60$ for the time taken to travel between A and B during off peak hours. **OFFFACTOR** is a constant that could be determined by considering issues that affect the flow of traffic and the value 60 converts hours into minutes.
- ONTIME** a variable whose values were computed by the expression $ONFACTOR \times 60$ for the time taken to travel between A and B during heavy traffic hours. **ONFACTOR** is a constant of peak/traffic periods. Multiplying by 60 changes the hours to minutes.

Attribute data for this layer were stored in the data base file, route.dbf whose structure is shown in table 17 below. There were four records for this file.

Table 17 Data structure for route.dbf

Field	Type	Width	Decimal	Comments
Normaltime	numeric	10	2	normal travel time
Totaltime	numeric	10	2	ideal travel time
Route_no	character	10	-	route identity
Offfactor	numeric	10	2	off peak constant
Onfactor	numeric	10	2	traffic constant
Descrip	character	50	-	route to be followed

4.5.2.2. Buildings

Under this heading, building footprints are used to represent buildings. The word building as used will refer to the footprints. Also included in this section is a noise buffer zone along major streets within which no buildings should be constructed.

Buildings

This layer represents graphic data for the footprints of the buildings. Data on buildings were not available so they were improvised by digitising three different building polylines. These were then arbitrarily placed within the study area in parcels using the 'copy' command in AutoCAD . In reality, footprints of buildings could be supplied by photogrammetric methods or input from architectural drawings or property assessment maps.

A component, BUILDING, was created having entity feature, polyline. Under this component, an internal integer variable, BD_ID was formed. This internal variable is also common to the component PARCELS that represent the lots (parcels) and database file OWNER.DBF that has the details of owners of parcels and their addresses. The layer, LOT_TXT was created to contain the unique identifiers (internal variable values) to the parcels and buildings. The values of internal variables were attached to the building entities using the option 'attach data and copy text inside entity' in the 'data linkage' submenu of TMS. External variables created for this component included: ADDRESS, FIRSTNAME, LASTNAME and MAINSTREET whose values were read in from database file, owner.dbf. ADDRESS is the mailing

post office box number, FIRSTNAME and LASTNAME represent the name of the property owner and MAINSTREET is the main street that runs past the property. The structure of this file is shown in table 18. External variables created and whose values were read in from the data base file, houses.dbf, are shown in table 19 below. The data structure for this file is shown in table 21. There were 184 data records in this data base file. Table 20 shows the variables computed in TIMS.

Table 18. File structure for owner.dbf

Field	Type	Width	Decimal	Comments
Lot_no	character	10	-	parcel identity
Firstname	character	10	-	owner's first name
Lastname	character	10	-	owner's last name
Mainstreet	character	10	-	street by the parcel
Address	numeric	10	0	owner's mailing address

Table 19. Variable values from houses.dbf

<u>Variable</u>	<u>Description</u>
LOTAREA	an external variable created to read values for the area of the parcel.
PIN	an external variable created to read values for the registration number of the parcel.
FUNCTION	an external variable created to read values for the function of the building.
DATE_CONS	an external variable created to read values for the date of completion of building.
HEIGHTOFBUILD	an external variable created to read values for the height of

	building in metres.
PERSONS	an external variable created to read values for the number of persons that occupy the building.

Table 20. Variable values created within TIMS

<u>Variable</u>	<u>Description</u>
DUADDRESS	a duplicate variable created to change ADDRESS values from integer to string type.
DUPERSONS	a duplicate variable created to change PERSONS values from integer to string type.
HOUSEVALUE	a variable whose values were computed by the expression LOTAREA/0.013. The value 0.013 is constant and could be arrived at by considering factors associated with valuation including location, age and building material cost.
BUILTAREA	an external variable created to read values for the parcel area occupied by the building. These values were initially extracted as graphic attributes.
PICTURE	a link variable created to link a scanned image of a building to the footprint.

The variable PERBUILTAREA represents the percentage area not occupied by the building to the total area of the lot and was computed by the expression:

$$\text{PERBUILTAREA} = \frac{\text{LOTAREA} - \text{BUILTAREA}}{\text{LOTAREA}} \times 100$$

The above expression was broken into three steps shown below because TIMS can not solve for it:

$$1. \text{LOTAREA} - \text{BUILTAREA} = \text{XAREA}.$$

2. (XAREA / LOTAREA) = PERXAREA.

3. PERXAREA X 100 = PERBUILTAREA.

Table 21. File structure for houses.dbf

Field	Type	Width	Dec	Comments
Bd_id	numeric	10	0	Identity of building
Builtarea	numeric	10	2	Area occupied by building
Lastname	character	10	-	values not read in
PIN	character	10	-	Registration number
Firstname	character	10	-	values not read in
date_cons	date	8	-	construction date
persons	numeric	3	-	persons in building
Annualrent	numeric	12	2	Annual rent paid
Const_mate	Character	15	-	Building materials
Buildheigh	numeric	4	1	Height of building
Bldingplan	character	5	-	Building plan number
Function	character	10	-	Function of building

Noise control

This layer contains graphic data for the buffer within which buildings should not be constructed because of noise pollution from vehicles using the main streets. The buffer location was arbitrarily chosen to follow along major streets. The location or position of this buffer could be arrived at by considering many factors such as sound propagation, meteorological conditions, volume of traffic among others. STREET layer and BUILDING layer were turned on to aid in tracing out the buffer.

A component, NOISECONTROL of polyline entity was formed. The internal variable was a string called BUFFERZONE. Queries carried out were in conjunction with the buildings layer and will be discussed later. No attribute data were stored for this layer.

4.5.2.3. Land management

Data related to land management are discussed here and includes parcels and city blocks.

Parcels

Data for this layer was imported as a DXF file from ARC/INFO. The original layer called a coverage in ARC/INFO, was edited by snapping arcs to nodes using the command, CLEAN. It was exported as a DXF file and then imported into AutoCAD/TIMS drawing. Topology was built with the command 'build topological polygons' found in the submenu 'utilities' of 'analysis/utilities' in TIMS.

A component called PARCELS was created with polylines as its entity feature. An internal integer variable LOT_NO was created for this component. Prior to this a layer called LOT_TXT had been created to contain the text or labels for each parcel. LOT_TXT and PARCELS layers were turned on with the PARCEL being the current layer. Internal variable data were attached to each parcel by the command 'attach data and copy text inside entity' under the 'data linkage' submenu of TIMS. External variables created included: ADDRESS, the address of the owner FIRSTNAME,

LASTNAME being the name of the owner, read in from the data base file owner.dbf shown in table 18. Values for external variables LANDUSE, DEVELOPED and REG_NO were read in from the data base file lots.dbf. This file had 423 records and its structure is shown in table 22.

Table 22. File structure for lots.dbf

Field	Type	Width	Decimal	Comments
Lot_no	numeric	10	0	Parcel number
Firstname	character	10	-	values not used
Lastname	character	10	-	values not used
Developed	logical	1	-	existence of activities
Reg_no	character	10	-	parcel registration
Mainstreet	character	10	-	street by the property
Area	numeric	10	2	area in square meters
Landuse	character	10	-	Land use classification

DEVELOPED refers to whether the property has structures constructed according to the zoning regulation and REG_NO is the registration number of the property.

Variables created within TIMS are shown in the table 23.

Table 23. Variable values created in TIMS

<u>Variables</u>	<u>Description</u>
DUPADDRESS	a duplicate variable created to change the values of ADDRESS from integer to string character to represent the address of the owner.

ANNUAL_TAX	a variable whose values were computed by the expression $AREA \times 0.55$ to represent tax collected on property annually. 0.55 is an constant that could be determined, in real situations, by considering factors like the building value and location of the parcel.
VALUE	a variable whose values were computed by the expression $GR.AREA \times 500$ to represent the value of the parcel. The value 500 is a constant was selected to compute the building value.
AREA	an external variable created to read values for the area of the parcel. These values were initially extracted as graphic attributes.

Statsblocks

This layer contains graphic data for the city blocks. A block is an area of a collection of parcels. The layer, PARCELS, was turned on but locked. A new layer, STATSBLOCK, was created to contain the city blocks. The blocks were drawn around the parcels as polylines using AutoCAD drawing functions. Nine blocks were drawn within this study area namely KILI01, KILI02, KILI03, KILIO4, GOLF01, NAIW01, MUGU01, KIBE01 and KENY01. The first four letters stand for the sublocation area that is:⁴ KILI for Kilimani, GOLF for Golf Course, NAIW for Nairobi West, KIBE for Kibera and KENY for Kenyatta Hospital sublocations. The polylines drawn were built into topological polygons using the command 'build topological polygons' in the 'utilities' submenu of 'analysis/utility' submenu of TMS.

A component, STATSBLOCKS was formed with feature entity type polyline.

⁴The Province of Nairobi is divided into administrative locations that are further divided into sublocations.

Internal string variable, BLOCK_NO was created under this component. An internal variable value similar to the block name were attached to each polygon. Statistical data variables were created under this component and included:

PARCELAREASTAT_AVERAGE, PARCELAREASTATS_COUNT and PARCELAREASTATS_TOTAL representing average parcel area, number of parcels and total area of parcels of block respectively; PARCELVALUESTATS_AVE, PARCELVALUESTATS_COUNT AND PARCELVALUESTATS_TOTAL representing average, number and total of the value of the parcels within the block respectively; and TAXCOLLECTED_AVERAGE, TAXCOLLECTED_COUNT and TAXCOLLECTED_TOTAL representing average, number and total tax collected of the parcels within the block respectively.

4.5.2.4. Sanitary services

This class includes sanitary features like sewers and sewer manholes. Data on these entities was not available and had to be improvised. Data input and manipulation for the features will be discussed.

Sewers

This layer stored the graphic data for the sewer network. Since graphic data for sewers were not available, the network was created by drawing line segments to connect to the buildings, and also to extend to form the network using AutoCAD drawing functions. SEWERS was made the current layer while PARCELS and BUILDINGS layers were turned on but locked.

A component, SEWERS, of line type entity was created. An internal string variable called SEWER_NO was created for this component. Internal variable values for the sewer segments were designed in a way that made it possible to recognize a main sewer or a connecting sewer. The geocoding was in the form SEW_X_MY where X was the number of the main sewer, and M stood for main sewer and Y was the section number of the main sewer. For the sewer connecting to buildings the form was SEW_X_CY where the X was the main sewer, C stood for connection and Y was the number of the connection. The command 'attach data and increment counter' was used to link the internal variable value to each sewer section. Other variables created are shown in table 24.

Table 24. Variables for SEWERS component

<u>Variable</u>	<u>Description</u>
SEWERFLOW	a network variable created to show the direction of flow of sewer waste. The exact direction for each sewer segment was entered on the screen.
SEWBLD	a relational variable created to link variables of BUILDINGS component to SEWERS. This links the variables into new variables of the form SEWBLD.? where the ? is replaced by the variables found in the component BUILDINGS.
SEWERADDRESS	a variable whose values were computed by the expression SEWBLD.DUADDRESS + " " to represent the address of the owner.
SEWERHOUSEID	a variable whose values were computed by the expression SEWBLD.BD_ID + " " to represent the building identity.

SEWERLENGTH	an external variable whose values were read in from the sewer.dbf file but had been initially extracted as graphic attributes.
SEWERNAME	a variable whose value was computed by the expression <code>SEWBLD.FIRSTNAME + " "</code> to represent the name of the owner.
SEWERPERSONS	a variable whose value was computed for the number of persons occupying the building by the expression <code>SEWBLD.DUPERSONS + " "</code> .
SEWERPOPULATION	a duplicate variable created to change values for SEWERPERSONS from integers to string type.
SEWERSIZE	an external variable whose values were read from the data file sewers.dbf to represent the diameter of the sewer.
SEWERSURNAME	a variable computed for the surname of the owner by the expression <code>SEWBLD.LASTNAME + " "</code> .
SEWERTYPE	an external variable created to read values for construction material of sewer.

Attribute data was stored in the data base file sewers.dbf. The structure is displayed in table 25 . This data file contained 338 records.

Table 25 File structure for sewer.dbf

Field	Type	Width	Decimal	Comments
Sewer_no	character	10	-	sewer pipe identity
Sewerflow	character	10	-	direction of effluent
Gr-length	numeric	10	2	length of pipe
Type	character	5	-	type of pipe
Size	numeric	4	0	pipe diameter

Sewermanholes

This layer contains graphic data for the sewer manholes. The symbol created was three small circle of sizes 5.82, 4.32 and 2.62 meters respectively within the scale. The inner circle was shaded for better visual effect. The symbol was saved as a block form called SEMAN. The manhole symbols were then inserted at appropriate locations on the SEWERS layer that was turned on but locked.

A component called SEWERMANHOLES was created whose entity type was an insert. An internal string variable was created called SEWMAN_NO. This variable was of the form SEWMAN_? with ? being the integer for each manhole. Other variables created are shown in table 26.

Table 26. Variables created for SEWERMANHOLES component

<u>Variable</u>	<u>Description</u>
DEPTH	an external variable created to read values for the depth of the manhole.
PLANREF	an external variable created to read values for the plans that pertain to the particular manhole. Data values were not available for this variable.
TYPE	an external variable created to read values for the type of the manhole.
SEWERINT	a relational variable formed to relate the sewer manhole to the nearest major road intersection. This allowed access to variables in the INTERSECTION component.
SEWDESCRIPTION	a variable whose values were computed by the expression SEWERINT.STREETS_MEETING + " " for the streets that meet at the intersection.
SEWINT_NO	a variable whose values were computed by the expression

SEWERINT.INT_NO + " " for the identity of the major intersection.

SEW_X, SEW_Y external variables created to read values for the XY coordinates of the manholes. These values were initially extracted as graphic attributes.

Attribute data for some of the variables above was read from the data file sewman.dbf the structure of which is shown in table 27. A total of 44 records were entered.

Table 27. File structure for sewman.dbf

Field	Type	Width	Decimal	Comments
Sewman_no	character	10	-	manhole identity
Gr_x	numeric	10	2	x coordinate
Gr_y	numeric	10	2	y coordinate
Type	character	6	-	manhole type
Depth	numeric	5	2	manhole depth
Planref	character	6	-	Data not available

4.5.2.5. Water supply

Data associated with water pipe networks is discussed and includes water valves, water meters, water manholes and water pipes.

Waterpipes

This layer represents graphic data for the water pipe network for the study area. The layers used include the BUILDINGS and PARCELS layers that were turned on

but locked. The water pipe network is a series of connecting lines where the line is the section between two pipe connections. The water pipe network was digitised on the screen using the AutoCAD draw commands because the data was not available.

A component, WATERPIPES was formed of entity type line. Under this component, an internal string variable, PIPE_NO was formed. Internal variable values were attached to each pipe section. The variable value was of the form 00X_S0Y where X was the identity of the main pipe and Y was a part of the main section line. S implies that the section is part of the main water pipe. For the interconnecting pipes the variable value was of the form 00X_C0Z where X was the identity of the main pipe, C stood for connecting pipe and Z was the connection number. Variables created under this component are shown in table 28.

Table 28. Variables created under WATERPIPES component

<u>Variable</u>	<u>Description</u>
PIPECONS	an external variable created to read values for the date of construction of the pipe.
PIPESIZE	an external variable created to read values for the diameter of the water pipe.
PIPETYPE	an external variable created to read values for the material of the pipe.
SEC_LENGTH	an external variable created to read values for the length of the pipe section. Values were initially extracted from the drawing into the data base file
FROM_ELEV, TO_ELEV	external variables created to read values for data on elevation of the beginning and end of the pipe section. There was no data associated with these variables.

MANHOLE_ID	an external variable created to read values for the closest manhole to a particular pipe section but no data was associated with this variable.
COST	a variable whose values were computed by the expression SEC_LENGTH X 234 to represent the cost of constructing the sewer. The value 234 is a constant that could be determined by factors like labour cost and materials in real situations.
WATERFLOW	a network variable created to show the direction of flow of water.

Attribute data were read in from the data base file waterpip.dbf whose structure is shown in table 29. A total of 373 records were entered in this file.

Table 29. File structure for waterpip.dbf

Field	Type	Width	Decimal	Comments
Pipe_no	character	10	-	pipe section identity
Type	character	10	-	pipe material
Size	numeric	3	0	pipe diameter in millimetres
Manholes	character	10	-	data not included
Cons-day	date	8	-	date pipe laid

Valves

This layer was created to represent graphic data for the water valves located on the water pipe network. The layer VALVE was formed and made current. Also turned on but locked was the layer WATER_PIPES. The symbol for the water valve was drawn in AutoCAD and saved as a block. The valve symbol was then inserted at

appropriate locations on the water pipe network.

A component, VALVE, was created that was of insert type entity. An internal string variable, VALVE_NO was created. Internal variable values were then attached to each valve. Other variables created are shown in table 30.

Table 30. Variables for VALVES component

<u>Variable</u>	<u>Description</u>
AMOUNT	an external variable created to read values for the amount of water, in gallons, consumed each month.
STATE	an external variable created to read values for the state of the valve: on or off.
VAL_X, VAL_Y	external variables created to read XY coordinates of the valves. Values for these variables were originally extracted as graphic attributes.

Attribute data were read in from the data base file valves.dbf that had 22 records. The structure of this file is shown in table 31.

Table 31. Data structure for valves.dbf

Field	Type	Width	Decimal	Comments
Value_no	character	6	-	identity of valve
State	character	3	-	value on or off
Amount_mnt	numeric	9	2	monthly water flow
Posit_x	numeric	9	2	x coordinate
Posit_y	numeric	10	2	y coordinate

Watermanholes

This layer was created to represent graphic data for the water manholes. The WATERPIPE layer was turned on but locked. A new layer, WATERMANHOLES was created and made current. The symbol for water manholes, two concentric circles, was formed in AutoCAD and saved as a block, MANHOLE. This was then inserted at appropriate locations on the water pipe network.

A component, MANHOLES, was formed of entity type insert. An internal string variable, MANHOLE_NO was formed under this component. Internal variable values were attached to each manhole. Other variables created under this component are shown in table 32.

Table 32. Variables created for MANHOLES

<u>Variables</u>	<u>Description</u>
DEPTH	an external variable created to read values for the depth of the manhole.
MANTYPE	an external variable created to read values for the type of manhole .
MAN_X,MAN_Y	external variables created to read values for XY coordinates of the manhole. These values were initially extracted as graphic attributes.

Table 33 shows the structure of data file waterman.dbf that contained data for the variables. A total of 29 records were in this file.

Table 33. File structure for waterman.dbf

Field	Type	Width	Decimal	Comments
Manhole_no	character	6	-	manhole identity
Posit_x	numeric	9	2	x coordinate
Posit_y	numeric	10	2	y coordinate
Type	character	3	-	manhole type
Depth	numeric	3	1	depth of manhole

Meters

This layer represents graphic data for the water meters located on the water pipe network of the study area. To facilitate placing water meters, the layer WATERPIPES was also turned on but locked. The symbol for meters, a circle with a cross, was created in AutoCAD and saved as an AutoCAD block and then inserted in the appropriate locations.

A component, METERS was created with entity insert. An internal string variable METER_NO of form MET_? was created. Internal variable data was attached to each meter by the command 'attach and increment counter' in the 'data linkage' submenu of TIMS. External variables created for this component are shown in table 34.

Table 34. Variables for METERS component

<u>Variables</u>	<u>Description</u>
WATERUSED	an external variable created to read values for amount of water used, in gallons, monthly.
MONTH_BILL	an external variable created to read values for the monthly bill as computed from the amount of water used.
METERHOUSE	a relational variable created to link components METERS and BUILDINGS. This allows access to variables created in METERS and BUILDINGS.
METADDRESS	a variable whose values were computed for the address of the owner of the meter by the expression METHOUSE.DUADDRESS + " ". METHOUSE.DUADDRESS is a variable accessed because of the relational variable METERHOUSE.
METLASTNAME	a variable whose values were computed for the surname of the owner of the meter by the expression METHOUSE.LASTNAME + " ". METHOUSE.LASTNAME is a variable accessed because of the relational variable METERHOUSE.
METOWNER	a variable whose values were computed for the first name of owner of meter by the expression METHOUSE.OWNER + " ". METHOUSE.OWNER is a variable accessed because of the relational variable METERHOUSE.
METBUILDING	a variable whose values were computed for the building number by the expression METHOUSE.BD_ID + " ". METHOUSE.BD_ID is a variable accessed because of the relational variable METERHOUSE.

Attribute data were read from the data base file meters.dbf. The file contained 193 records. Table 35 shows the structure of this file.

Table 35. Data structure for meters.dbf

Field	Type	Width	Decimal	Comments
Meter_no	character	10	-	meter identity
Waterconsu	numeric	10	2	water used monthly
Gr_x	numeric	10	2	x coordinate
Gr_y	numeric	10	2	y coordinate
Month_bill	numeric	10	2	monthly bill paid

4.6 Analysis functions in TIMS

TIMS analysis functions have been used to address the following simulated questions. Reports and plots have been prepared in each case for better visual effects. These analysis problems may not be exhaustive but are provided as examples of the analysis expected from TIMS software.

4.6.1 Water supply

The duties of the Department of Water Supply of the City of Nairobi include the provision of safe drinking piped water for its residences among others. Complaints received from the city's health officials indicate that the water received in some areas of the city is contaminated. On further investigation it was discovered that ductile iron pipes that were most susceptible to contamination. After a period of time, the iron pipes rust and break thus allowing in poisonous elements from surrounding soils. The Department has decided to replace these water pipes. At the same time pipe sizes will

be increased to cater for the increasing number of consumers. Since the Department is working within a very tight budget, only top priority cases will be considered. Factors used to determine the urgency of pipe replacement are: pipes laid before January 1950, pipes with diameters 100 - 400 mm, and pipes made of ductile iron. The Department would like to have the following information:

- (i) the pipes that are made of ductile iron.
- (ii) pipes whose diameters are between 100 and 400 mm.
- (iii) pipes that were laid before January 1950.

The Department would be closing off some water valves and would need to identify consumers that will be affected by this action. The amount of water consumed each month will be determined so that water trucks will be mobilised to supply water to the consumers during the construction period.

Procedure

The graphic data layer involved in this analysis was the WATER_PIPES layer. A filter was created for each of the above requirements. The expression, WCMATCH 'DUC. IRON' under the variable PIPETYPE created a filter, WATFIL1 that selected all the pipes made of ductile iron. The pipes selected were coloured as shown in figure 9. A report, Appendix 1, gives information on the 29 selected water pipes.

Under the variable PIPESIZE, the expression >100,<400 was introduced to create filter, WATFIL2 that shows all pipes whose diameters range between 100 and 400 millimetres. The selected pipes are shown in figure 10. A report, appendix 2,

Figure 9. Ductile iron pipes

WATER PIPE NETWORK

Figure 10. Pipes of size 100-400 mm

prepared shows the 191 pipes whose diameters were between 100 and 400 millimetres. For the pipes laid before January 1950, the expression <19500101 was used under the variable PIPECONS in the filter WATFIL3. The selected pipes are displayed in figure 11. A report, appendix 3, was produced for the 234 selected pipes.

The Department could not replace all the 454 pipes immediately because of financial constraints. The most urgent cases would be the pipes that were made of ductile iron, were between 100 and 400 millimetres and that were constructed before January of 1950. A filter, WATFIL4, was formed to address this request. The expression used in the filter WATFIL4 was: >100,<400 for the variable PIPESIZE, <19500101 for the variable PIPECONS, and WCMATCH 'DUC. IRON' for the variable PIPETYPE. The selected pipes were saved as WATSET4 and are shown in figure 12. A report, appendix 4, was produced for the 29 pipes that required an immediate response. FROM ELE and TO ELE in the report refer to the height above sea level of the start and the end of a pipe section but data for these fields was not available.

The Department also needed to know the valves that had to be closed. These were easily identified by looking at figure 12 that shows the affected pipes in a different colour. A report shown in table 36, was produced to show the valves to be closed. VALVE_NO, X and Y, STATE refer to the valve identity or reference file, position of the valve, and whether the valve was off or on respectively.

Figure 11. Pipes laid before Jan. 1950

Figure 12. Pipes to be replaced

Table 36. Valves to be closed for construction

<u>Valve_no</u>	<u>X</u>	<u>Y</u>	<u>State</u>	<u>Water (Gallons)</u>
VAL_7	255689.64	9858002.42	OFF	35501.23
VAL_8	255602.19	9857962.53	OFF	40531.02
VAL_6	256764.50	9857965.50	OFF	75021.02
VAL_14	256111.27	9857665.03	OFF	15356.65

Network analysis was carried out on the water pipe network to identify the buildings, water manholes and meters that would be affected by the closure of water valves. Figure 13 shows the affected buildings in red. A combined report, Appendix 5, was produced showing the owners of the building and manholes involved in the project. MANREF, TYPE, DEPTH , X and Y refer to the reference file/identity, type, depth and geographic position of the manhole respectively. BLDG refers to the building number.

The Department was also interested to know how the closure of the valves would affect water consumption so as to prepare alternative means of providing water to the affected consumers. A report, appendix 6, was prepared showing the affected consumers and the amount of water consumed for one month. The total water consumption and water bill for the consumers is 24476.20 and 1223.80 (C\$ 24.48) respectively. BOXNO stands for the mailing address of the CONSUMER, METERNO, AMNT And BILL refer to the meter identity, amount of water in gallons recorded monthly and the monthly water bill in Kenya shillings respectively. BLDG refers to

BUILDINGS AFFECTED BY PIPE RECONSTRUCTION

Figure 13. Buildings affected by pipe reconstruction

the building number.

4.6.2 Sanitary services

The Department of Treatment Works and Sewers is embarking on Phase III of sewer recreation and expansion project in order to accommodate the projected consumer growth within the next century. Phase III project involves the following activities:

- (a) Expansion of small sewers according to the new sewer specifications that sewers leading to buildings should have a diameter of 200 millimetres or more.
- (b) Replacement of clay sewers with polyvinyl chloride (PVC) sewers.

The Department is working with a very tight budget and will need to identify cases that require immediate attention. In consultation with the Department of Social services and Health, the following would be given top priority: sewers that were attached to buildings having more than two occupants, had a diameter below 200 millimetres, and were made of clay. Affected consumers will need to be informed at least two weeks before the start of the project.

Procedure

The layers involved in this query were the SEWERS and BUILDINGS layer. A relational variable had been created under the component SEWERS. This variable creates a link between the variables of the components SEWERS and BUILDINGS. A data filter, SEWFIL, was formed to show clay sewers of sizes less than 200

millimetres and serving buildings or more than three occupants. The expression used in the filter was: WCMATCH 'CLAY' for the variable SEWERTYPE, <20 for the variable SEWERSIZE and >3 for the variable SEWERPOPULATION. This data filter was then applied to the whole sewer network. The selected sewers were saved as a set, SEWSET, and then coloured to differentiate them. Figure 14 shows the selected sewers in a different colour. A report, appendix 7, was generated to show further details of the selected sewers. The cost of replacement is 15975696.00 (C\$ 319513.92) Kenya shillings. SEWERID is the sewer reference to a file, BLDG is the building identity, BOXNO is the mailing address of the owner, LENGTH, SIZE and COST refer to the length, diameter and construction cost of the sewer respectively.

Heavy rains experienced within the city have resulted in the flooding and blockage of many sewers. The effluent from the sewers is flowing out from sewer manholes. Environmentalists and Health inspectors concerned about the repercussions of this catastrophe have asked that people within 120 meters of the sewer manholes be informed of this hazard. The Department of Treatment Works and Sewers identified the manholes and now needs to identify the parcels around them that would be affected. The Department would also like to know which of these are located within major intersections so that a suitable work plan is worked out for maintenance.

Figure 14. Selected sewers for reconstruction

Procedure

The analysis function used for this was the 'proximity analysis' in the 'analysis\utilities' menu of TIMS. The feature used was the sewer manhole as a point and a radius of 120 meters was selected for the proximity analysis. Figure 15 shows the affected sewer manholes and the area around them. The components searched for within the radius were the PARCELS. A report was produced to show these affected parcels (appendix 8). SEWMAN_NO, LOT_NO and REG_NO represent the identity of the sewer, the parcel identity and the registration of the parcel respectively. Within the SEWER component, a relational variable SEWERINT had been created and was used to identify the manholes located in road intersections. Table 37 is a report showing sewer manholes within intersections. SEWMAN_NO and INT_NO represent the sewer identity and the major intersection identity.

Table 37. Sewermanholes located within road intersections

<u>Sewman_no</u>	<u>Int_no</u>	<u>X</u>	<u>Y</u>
sewman_13	INT_1	256675.17	9858458.77
sewman_19	INT_3	257006.34	9857975.35
sewman_24	INT_17	255561.68	9857680.08
sewman_26	INT_15	256442.57	9857677.80
sewman_32	INT_13	255694.53	9857335.44
sewman_34	INT_11	255458.76	9856762.26
sewman_32	INT_13	255694.53	9857335.44
sewman_38	INT_9	256224.64	9857025.71

PARCELS CLOSE TO OVERFLOWING MANHOLE

○ 120 METRE RADIUS

• SEWER MANHOLE

SCALE 1 : 14000

Figure 15. Parcels close to overflowing manhole

4.6.3 Land Management

At the end of every fiscal year, the City evaluates the amount of tax collected from its residents. Based on the projected budget and the revenues it has, the City can then decide to lower or increase the taxes during the next fiscal year. TIMS software was used to analyze and output this information.

Procedure

A statistical bar graph was produced to show the annual tax collected by parcels in the area. This analysis was done using the command 'business graphic/bar graph' in the 'analysis/utility' submenu of TIMS. The component used was PARCELS and the variable selected was ANNUALTAX. The seven intervals chosen for the annual tax ranged from 0 - 1000(0 - C\$20), 1000 - 2000(C\$20 - 40), 2000 - 4000(C\$40 - 80), 4000 - 6000(C\$80 - 120), 6000 - 10,000(C\$120 - 200), 10,000 - 40,000(C\$200 - 800) and Over 40,000(C\$800) Kenya shillings. Figure 16 shows the bar graph representing annual tax collected by parcels for the study area. The horizontal axis represents the annual tax paid in Kenya shillings by thousands and the vertical axis shows the number of parcels paying tax within that range. A pie chart was also produced to show the percentage tax collected by block (figure 16). For this query the STATSBLOCK component was used. This analysis was done using the command 'business graphic/pie chart' in the 'analysis/utility' submenu of TIMS menu. The numerical variable used was the TAXCOLLECTED_TOTAL that shows the total tax collected from each block. The string variable used was the BLOCK_NO. The

PERCENTAGE OF TOTAL TAX COLLECTED BY BLOCK

ANNUAL TAX BAR GRAPH

Figure 16. Graphs for tax purposes

Figure 17. City blocks

blocks and parcels are shown in figure 17.

Comments

The block KENY01 contributes the most annual tax. The lowest percentage of tax is collected from KILI03. An explanation for this could be that the KENY01 block has more parcels that are used for industrial purposes as seen from the land use map (figure 18). Taxes on parcels for industrial use are the highest. About 163 owners pay amount of tax between 2000(C\$40) and 4000(C\$80) shillings. Only 25 pay taxes over the amount of 40,000(C\$800) Kenya shillings.

The City administration may like to review its zoning policies. Before this, information on current land uses needs to be collected and displayed. Tims thematic analysis function was used to produce a land use map by parcel for the area. Nine land use categories were identified namely: Agriculture, Education, Residential, Commercial, Government activities, Recreation, Industrial, Multi-purpose, and Unknown.

Procedure

The layer used in this analysis was PARCELS. The command 'thematic analysis' in the submenu of 'analysis/utilities' submenu of Tims was used. The variable selected to map this was LANDUSE in the PARCELS component. Land use categories were mapped and are displayed in figure 18.

Figure 18. Landuse by parcels

Comments

Parcels towards the southern part of the area are mainly for industrial use. About half of the area is used for residential purposes and education institutions are concentrated towards the northern part of the area. The distribution of recreation facilities is not evenly spread and agricultural use is limited to a few parcels. Land use for a few parcels was mapped as unknown.

4.6.4 Transport utilities

The Department of Transport keeps statistics on the flow of traffic within major road intersections. Data are collected for each major road intersection on the flow of human and vehicular traffic, and the road traffic accidents. These data were used to determine the roads that needed to be expanded to accommodate projected traffic growth within the next century. A road widening buffer was designed along the streets that would require expansion. The buffer intersected parcels on either side of the road. The City would have to acquire this land and pay compensation for it.

Procedure

Two layers PARCELS and ROADWIDENING were involved in this analysis. The command 'polygon overlay' in the 'analysis/utility' submenu of 'TIMS' was invoked. The variables used were: ROADWIDBUFFER from ROADWIDENING component and LOT_NO from component PARCELS. A new component, ROADWIDENING_PARCELS was formed for layer ROADWIDENING_PARCELS

that was created as a result of intersection of PARCELS and ROADWIDBUFFER layer. LINK_PARCELS and LINK_ROADWIDENING, handles to PARCELS and ROADWIDENING components were also created. The handles allowed access to data in the two components ROADWIDENING and PARCELS. Variables created from the intersection are shown in table 38.

Table 38. Variables created for ROADWIDENING PARCELS component

<u>Variable</u>	<u>Description</u>
ROLOTFIRSTNAME	a variable whose values were computed by the expression LINK_PARCELS.FIRSTNAME + " " for the first name of owner.
ROADLOTSURNAME	a variable whose values were computed by the expression LINK_PARCELS.LASTNAME + " " for the surname of owner.
ROADLOTADDRESS	a variable whose values were computed for the mailing address of the owner by the expression LINK_PARCELS.DUPADDRESS + " ".
ROADLOTAREA	a variable whose values were computed for the area of parcel within the widening buffer by the expression GR.AREA + 0.
ROADLOTNO	a variable whose values were computed by the expression LINK_PARCELS.LOTNO + 0 for the parcel identity.

A report showing the parcels affected by road widening was produced (appendix 10). LOTNO and REGNO are the parcel number and its registration number. Figure 19 shows the results from this analysis.

AREAS TO BE ACQUIRED FOR ROAD EXPANSION

Figure 19. Areas to be acquired for road expansion

The Department of Transport would also like to identify the streets that are in bad condition. These are streets that have potholes, have dug up sections, whose drainage system does not work properly, and are prone to flooding when it rains. The Department plans to resurface these roads when funds become available. For each street, ground inspection as to its condition was done and categorised into three namely good, average and bad condition according to a set criteria. These data were entered into the database file STREETS.DBF in the field CONDITION. TIMS was used to analyze and show the streets that were in bad condition.

Procedure

The layer STREETS was used in this analysis. A filter, STRFIL, was formed to show those streets that were in bad condition. The expression used for this was WCMATCH "BAD" for the variable CONDITION. The selected streets were coloured to differentiate them (Figure 20). The report in Appendix 10 was produced to show the streets in bad condition. The cost of repairing the roads will cost about 1,055,438,400 (C\$ 21,108,768) Kenya shillings.

TIMS analysis functions were used to determine the bridges that were liable to collapse during the rainy season. For this, the layer BRIDGES was used. A filter, BRIDFIL, was formed to show the bridges with clearance between 0 and 2.4 metres. The clearance is the distance between the level of the river and the bridge. The expression used was >0,<2.4 for the variable CLEARANCE in the BRIDGES

STREETS IN BAD CONDITION

STREET

— STREET IN BAD
CONDITION

SCALE 1 : 14000

Figure 20. Streets in bad condition

component. Figure 21 shows the location of the bridges and table 39 shows the report for bridges that are likely to collapse. Fea_onbrid, fea_cross and clr represent the feature the bridge is on, the feature the bridges crosses, and the clearance of the bridge respectively.

Table 39. Location of Bridges liable to collapse

<u>Brid_no</u>	<u>type</u>	<u>fea_onbrid</u>	<u>fea_cross</u>	<u>clr</u>
3	steel	Mbagathi Road	Ngong River	2.1
7	stone	Mbagathi Way	Ngong River	1.5
6	stone	Mbagathi Way	Motoine River	2.0
10	stone	Uhuru Highway	Ngong River	2.3

The following analysis was done to experiment with locating the shortest route between two places, A and B. This was done by digitising possible routes that could be followed from A and B (figure 22). The analysis 'business graphic/bar graph' in the submenu of 'analysis/utilities' submenu was used. The component used was the ROUTEALLOCATION and the numerical variables used were OFFTIME, ONTIME and TOTALTIME. OFFTIME, ONTIME and TOTALTIME represent the time taken to travel between A and B during the off peak, traffic and ideal traffic conditions. Three bar graphs for the different times are shown in figure 22. The colours for the bars correspond to the route colours for simple interpretation. A report, table 40, was also generated for this analysis.

BRIDGES

STREET

BRIDGE

SCALE 1 : 2500

Figure 21. Bridges

TRAVEL TIME BETWEEN POINT A AND B

SCALE 1 : 14000

Figure 22. Travel time between point A & B

Table 40. Travel time between point A and B

<u>Route_no</u>	<u>Distance</u>	<u>Offtime</u>	<u>Ontime</u>
ROUTE_1	1557.64	1.80	3.60
ROUTE_2	2729.91	1.20	1.80
ROUTE_3	1883.37	0.60	3.00
ROUTE_4	1829.37	1.80	1.20

Comments

The shortest route can be picked out easily by looking at the shortest bar graph for each category.

4.6.5 Buildings

Residents living along major streets are in danger of going deaf from the amount of noise produced by the vehicular traffic. The City issued a new guide line stating that along major streets, a noise buffer is identified within which no buildings should be constructed. For the buildings already within the buffer, the City agreed to let the buildings stand if the percentage of the building within the buffer was less than 24. The City required information on the percentage of building within the buffer and the affected occupants. This information was produced using the polygon overlay function in the 'analysis\utility' submenu of TIMS menu. Components used were NOISECONTROL and BUILDINGS. This analysis produced a layer NOISECONTROL_BUILDING that was renamed to BUILDINGBUFFER1. The components BUILDINGS and BUFFERZONE variables were linked by a relation so that access to variables in both the BUILDINGS and BUFFERZONE components was

possible. The links are named as LINK_BUILDINGS, and LINK_NOISECONTROL and are handle numbers of the BUILDINGS and NOISECONTROL components.

Variables computed for the intersection are shown in table 41.

Table 41. Variables for NOISECONTROL BUILDINGS component

<u>Variable</u>	<u>Description</u>
BLDADDRESS	a variable whose values were computed by the expression LINK_BUILDINGS.DUADDRESS + " " for the postal address of the owner of building.
GIVENNAME	a variable whose values were computed by the expression LINK_BUILDINGS.FIRSTNAME + " " for the first name of owner.
SURNAME	a variable whose values were computed by the expression LINK_BUILDINGS.LASTNAME + " " for the surname of the owner.
BLDAREA	a variable whose values were computed by the expression GR.AREA + 0 for the intersection area of the building with the buffer.
DECBLDAREA	a variable whose values were computed by the expression LINK_BUILDING.BUILTAREA-BLDAREA for the remainder of the building not in the buffer.
PERBLDBUFF	a variable whose values were computed by expression (BLDAREA/LINK_BUILDING.BUILTAREA) X 100 for the percentage of building in buffer zone.

A report, table 42, was prepared to show the buildings that would have to be pulled down. BDID and % BLDG represent the identity of the building and the percentage of building footprint within the noise buffer. Figure 23 shows the buildings located in the buffer.

Table 42. Buildings located within noise buffer

<u>bdid</u>	<u>owner</u>	<u>address</u>	<u>% bldg</u>
90	KANDA WAFULA	245	78.41
91	BONGOMAN NELIMA	356	59.81
92	RESINTA NAKHANU	350	58.56
93	MALI MUNDI	121	26.54
126	DUBIGA ASALAM	410	24.80
130	SHAH KUMAR	245	87.87
138	JOHN LUGANIA	501	56.84
144	DUBIGA ASALAM	196	46.00
145	PATEL MOMMAR	177	41.40
190	CHARLES TOTEMI	634	81.17
202	MIKE MAKUNDA	297	38.14
203	WAMBUI WANJIRU	373	66.11
207	NYONGESA ALFAYO	653	34.17

The City may like to know the buildings valued between a certain range. For instance the buildings valued between 700,000(C\$14,000) and 1,000,000(C\$20,000) Kenya shillings were selected by creating a filter BLDFIL1. The expression used was >700,000,<1,000,000 for the variable HOUSEVALUE. The selected buildings are shown and shaded in a different colour from the rest in Figure 24. A report on the buildings, was prepared and is shown in appendix 12.

Scanned images of the building were attached to the footprints of the buildings. A link variable called PICTURE was created in the BUILDINGS component to link a scanned image of a building to the footprint By clicking on the variable PICTURE in the buildings query box, a scanned image of the building is brought up on the screen.

BUILDINGS IN BUFFER

Figure 23. Buildings in buffer

BUILDINGS VALUED BETWEEN 0.7 AND 1 MILLION SHILLINGS

STREET

BUILDING

ES VALUED 0.7 TO 1 M

SCALE 1 : 14000

Figure 24. Buildings valued between 0.7 and 1 million shillings

4.7 Conclusion

The objective of this pilot study was to investigate the suitability of GIS, using TIMS software, to managing infrastructure data for a section of the Province of Nairobi. The study area was selected to represent a variety of urban infrastructure facilities. Although a lot more data entities were entered into the GIS, only some were selected to demonstrate the analysis functions of TIMS. The simulated queries are not exhaustive but represent possible questions that may arise in the course of the daily work of an urban municipality. TIMS was used as a tool to aid in identifying areas that required emergency measures, and also as an inventory to store information on infrastructure facilities.

Graphic and attribute data for most entities were not available but the analysis functions done, on the improvised data, proved the capability of this software to addressing infrastructure management issues.

Although most analyses processes took a few minutes, the creation of the database had taken over four months. It is difficult to show some analyses on hard copy because some of these are done interactively on the screen. The power of GIS analysis functions can best be appreciated when viewed on the screen rather than as displayed on plots.

Problems experienced for data accuracy and quality when implementing this study will be discussed in chapter five. The next chapter discusses factors in data accuracy and quality for GIS data. The study area was evaluated using these factors.

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CHAPTER FIVE

DATA QUALITY AND ACCURACY

5.1 Data quality and accuracy

Data quality and accuracy is of much importance to a GIS that it needs special attention. Since GIS technology provides the ability to integrate data from different sources and thus enables many users to access this data, it should be of a quality and at an accuracy suited to the required task. Therefore, the quality and accuracy of GIS data should be determined to alert users to its reliability. Data quality is defined as the degree to which data is suitable for the intended task¹ while data accuracy refers to the closeness of a result from the 'true' value.² Data quality is best addressed by the users of the data through identifying sources of errors. For GIS data, this will entail looking at sources of errors for both graphic and attribute data and how these errors are propagated at the various stages of collection, conversion, manipulation, analysis, and dissemination of data. The measure for data accuracy requires that a value be set to be the 'true' value from which the deviations of the other values are measured. It is often difficult to separate data quality and data accuracy as these are two interrelated factors since for data to be of required quality, errors have to be identified and eliminated where possible and the removal of errors in some cases improve the accuracy of data.

This chapter discusses factors that will affect data accuracy and quality of the

the pilot study area is evaluated using these factors. Some solutions to ensure that the errors are minimised are given.

5.2 Factors affecting graphic data accuracy

The most important source of graphic data for an urban area is the map.^a Positional accuracy of features portrayed on a map will affect the quality of the data entered into a GIS and depending on the skill of the cartographer in plotting features, the errors due to plotting will be transmitted to the digital data during the data conversion. Positional accuracy has two aspects to it:³ horizontal accuracy and vertical accuracy. Horizontal accuracy refers to how accurately a feature can be located on the ground by using the map. A boundary plotted on a land use map at the scale of 1:2,000 will only be accurate to about two metres assuming that the cartographer could plot to within a millimetre. A plan at scale of 1:200 on the other hand will be accurate to two centimetres. Vertical accuracy refers to the determination of the correct height from a map for the feature located on the ground. Positional accuracy is evaluated by the Root Mean Square (RMS) which is the square root of the sum of the deviations of the value from the expected or true position. This evaluation will not be correct for boundaries of features that are not clearly defined like forest boundaries or flood areas that vary depending on the climatic seasons. For raster type data, the positional accuracy is dependent on the resolution at which the data was collected. For a SPOT

^aThe word map is used to include architectural plans, engineering plans, land use maps and other map products.

imagery, the smallest available information is on a 20 metre by 20 metre pixel. This obviously is too coarse for most urban data use.

The process used in converting data from analogue sources will affect the quality and accuracy of the final data as errors may be introduced due to operator fatigue.⁴ Conversion by manually digitising or scanning is less accurate than entering the data at the key board. For example, boundaries of parcels will be more accurate entered as a series of coordinates or relative distances than digitised from an existing map thus making the data of a quality that engineers can use.

The scale of the map or plan used for initial data entry will strongly affect the accuracy of the map data⁵ since features to be included on a map are determined by the scale. Assuming that the smallest unit that can be differentiated by the human eye is 0.5 millimetres, at a scale of 1:10,000, only features greater than 10 metres will be mapped. A six metre road therefore will not be mapped but if this road was one of the major highways through a small town, it would be shown at an exaggerated road width. Data accuracy and quality of data entered in a GIS will be affected when the data on plans or maps used as sources was mapped in different coordinate systems. For instance, there exists at least three coordinate systems in Kenya for mapping data namely, the UTM, the Cassini Soldner and the local datum. Maps are produced using one of the three systems and in order to integrate data from the different systems, conversion from one system to another is required. Errors are introduced during the conversion due to loss of precision as the parameters used may have to be rounded to an acceptable value.

5.3 Factors affecting attribute data

Attribute data describes the graphic entity and factors that affect its accuracy and quality are the manner of data classification, and the resolution at which data was collected.⁶ Classification of attribute data prior to entry into the computer will vary depending on the needs of the user but all the possible occurrences of an event should be identified to ensure that all the data is classified. For instance, defining classes for land use requires that all possible types of commercial activities be included (figure 25).

Figure 25. Example of land use classification.

In the above classification, a service like restaurants will not be included as it does not belong to any of the classes shown above.

The resolution at which the original data was collected will affect the data accuracy and therefore its suitability for the required task. Although demographic data collected at the household level is more accurate than that collected at the city block level, agencies requiring it will have to be content with the less accurate data

collected at the city block level especially since the cost of collecting data at household level is prohibitive. Analysis produced with this data will contain errors propagated as a result of generalising or interpolating data for the city blocks.

5.4 Factors affecting both graphic and attribute data

The users of the final data will normally determine the level of accuracy with which data needs to be entered into a GIS for it to be suitable for the particular purpose.⁷ If the data were required by planners to show land use categories, then positional accuracy may be sacrificed at the expense of attribute accuracy. On the other hand, engineers may be more interested in the positional accuracy of a sewer line than its attributes. Completeness of data refers to whether all the required data was entered.⁸ For example, the graphic data needs to be checked to ensure that all the possible street sections were entered in the data base. Similarly for attribute data, entries need to be checked for completeness. The process of data input will affect the accuracy of the data. Attribute data is normally entered at the key board to a data base file and the precision with which this is done will affect the final data accuracy. Length of a pipe section entered as 2003.00 is different from 200.300 and analysis produced with this data will be misleading.

Accessibility to data sources will determine the quality and accuracy of the data entered in a GIS.⁹ Maps prepared for military use are always more accurate than the ones for civilian use but are usually inaccessible to the public. Since original demographic data collected at the household level also is not accessible to most

departments because of privacy regulations, agencies will use the available data that may not be as accurate thus affecting the results from the analysis.

Logical consistency refers to whether a graphic feature has been linked with its correct attribute data and vice versa.¹⁰ Attribute data for a parcel, for instance, not linked to the correct graphic entity leads to misinterpretation of the information generated as the inconsistency is propagated to the analysis stage.

Original data collection procedures affect both the quality and accuracy of data entering a GIS.¹¹ For example, boundaries of parcels digitised directly from aerial photographs are less accurate than actual ground measurements carried out for the parcels. Aerial photographs come with their own set of errors that include the tilt, swing, the dip, the altitude of the aircraft at the time that the photographs are taken and using these photographs as sources of data will propagate some of these errors into the digital data.

The time taken to enter data into a GIS will determine its currency and therefore its accuracy especially for attribute data.¹² It could take one year to enter data on the streets by which time conditions of streets will have changed and updating will be required to correct this. In situations where there is no data for the required applications, agencies have to collect their own data. This increases even more the time expended because data collection and conversion of this data to digital form takes time.

When all the required data has been entered into the GIS and all the possible errors identified, other factors that will affect the accuracy and quality of the final

products will be limitations in software, hardware and the manner of interpretation of the final products by the users. The procedures in the software for manipulating data will affect its accuracy.¹³ For instance, lines are snapped onto the nearest points by identifying a snap distance and in some cases lines may be snapped to the wrong point. The small road section, ab is reduced to point a as shown by figures 26 (a) and (b) thus displacing the road segment to the left of a.

Figure 26. Example of a long intersection (a), and collapsed intersection (b)

Another factor that will affect the final product is the data storage facilities, especially the properties of the database.¹⁴ The design of the attribute data base is limited by the precision or number of characters that can be handled in the data fields and this requires that values with long names be truncated and numbers be rounded. The limitations of graphic data models also require that certain manipulations be carried out on the source data to enable its entry into a data base. In order to use raster type data in a vector based environment, raster to vector conversion will be carried out and this will introduce position errors especially along the boundaries as the raster model does not define boundaries or line type features as precisely as the vector model.

Spatial analysis functions affect the results of the final product especially if attention is not paid to the initial data collection procedures, the nature of the data and its representation in digital form.¹⁵ Overlaying a noise buffer, that is not a discrete boundary, with parcel layer that is a discrete layer will produce results that are not realistic because the definition of a noise buffer zone due to the nature of propagation of sound waves, is not as precise as the definition of a parcel boundary that may be described with survey measurements.

Final products from the system will be affected by the limitations of the plotting process.¹⁶ For example, pen plotters use pens of certain thickness, after plotting for some time, the pens become flat and the size of a plotted boundary line thickens. The pen speed and the resolution of the plot as well will introduce position errors so that the length of a line measured on these plots will not be accurate.

People using GIS data are often not aware of the limitations of the data sources.¹⁷ This leads people to make assumptions and conclusions about the analysis produced from GIS. Data users should be alerted to GIS processing, sources of errors, limitations of software and hardware, and on the proper use of the data.

5.5 Evaluating the pilot project.

The pilot project will be evaluated based on the factors stated above. Errors arising from data sources, conversion, and processing will be described. Problems with the use of the products from data analysis will be addressed.

5.5.1 Factors in data sources

The maps used for data input were outdated. The outline of the Province of Nairobi was digitised from the Nairobi Parliamentary constituencies sheet scale 1:50,000 published in 1991 for the purposes of elections. A copy of the Water and Storage Supply map used was prepared in 1989, and a copy of the Sewer Master plan used, was prepared in 1974. Streets and parcels were digitised from the City of Nairobi, Map and Guide at scale 1:20,000 in the UTM zone 37 coordinate system last revised in May 1978. As the scale of this map made it uncomfortable for digitising, the required area on the map was enlarged by photocopying and pasting the sections together. Errors are already introduced at this point from the photocopying and pasting process. Large scale survey plans received later from Nairobi were accurate but the coordinate system for these plans was the Cassini Soldner coordinate system and integrating these plans into the digital map, that was in the Universal Transverse Mercator coordinate system, introduced positional errors.

Coordinates for control points used for digitising parcels and streets were measured from a topographic map series Y731 sheet 148/4 edition 1967 7-SK of scale 1:50,000 UTM zone 37. At that scale, the smallest distance that can be measured on the map will represent 50 metres on the ground. The identification of the control points on both the topographic map and the photocopy was not precise because some features were not clear on the photocopy. For the Province of Nairobi map, coordinates had to be derived from two different topographic maps: series Y731 sheet 148/4 edition 1967 7-SK scale 1:50,000 and series Y503 sheet SA-37-5 edition 5-SK

1980 of scale 1:250,000 (table 43). Since these maps were produced at different times, 1967 for the former and 1980 for the latter, errors were introduced as the accuracy of a measured feature on both maps is different. The thickness of the Province of Nairobi boundary also introduced errors as the exact coordinates of selected control points falling on the boundary had to be approximated.

Table 43. Control points for Province of Nairobi

Points	X	Y	Place	Map Source
1	239 750	9 853 000	Left	Y503 SA-37-5
2	276 900	9 858 550	Dandora	Y731 148/4
3	256 775	9 854 075	South	"
4	288 750	9 859 125	Right	Y503 SA-37-5
5	264 500	9 872 000	North	"

Graphic data for the water pipe, sewer, blocks, manholes was all improvised as it was not available at the resolution required for the study area except for the street names. Although the graphic features were improvised, the attribute data extracted from the entities including area, length and coordinates of points was real in that it represented the correct measurements of the graphic entities.

5.5.2 Data conversion factors

Digitising of the graphic data for streets and parcels was carried out in the ADS module of ARC/INFO. Prior to digitising, control points with known ground

coordinates were identified on the map. Using these control points, the digitised information was transformed from digitiser coordinates to the UTM coordinate system. The Root Mean Square(RMS) was computed and is shown in table 44 below. In an ideal situation, the RMS should be zero.

Table 44. Error analysis for data transformation

Map	RMS input	RMS output	Scale in Y	Scale in X
Nairobi	0.3712850	477.8949	1286.5620	1287.3835
Study area	0.4662315	114.0826	237.2905	252.0912

It can be seen that the scale varied in X and Y direction for both maps.

Ultimately the scale should be the same in both directions or close to one another. The large RMS values for output may be as a result of the errors propagated from using photocopied maps and using maps not prepared for topographic detail. Procedures in converting the data that included the operator fatigue, and the precision at which the digitising and measurement of the coordinates for the control points was carried out also contributed to the large RMS.

Before features were digitised, geocoding was done to give them a unique identity that was later to be the internal variable. Sometimes due to human errors, the same unique identity was given to more than one parcel and if this was not discovered in time, the error was propagated up to the analysis stage where the query of the parcels involved would display incorrect information.

5.5.3 Factors in GIS processing

Positional errors were introduced during data processing when overshoots and undershoots were snapped to the nearest line or point, and for double street lines that did not coincide with parcels boundaries, when editing was done in order to ensure that the boundaries coincided. Since the specified field length for field names in dBASE IV is 10 characters only, long field names had to be abbreviated. The field to store date of construction in the streets.dbf database file was abbreviated to cons_date. Variables within some fields could contain 20 characters only and so for variable values longer than 20 spaces, values were truncated. The street name Arwings Kodhek Road, for example, was truncated to Arwings Kodhek.

When data from the graphics entities was linked to the attribute database with TIMS data linkage function, errors were introduced in the automatic linkage. Some parcels for instance had the same identifier after the linkage and in land use classification by parcels (figure 18), some activities were not classified and so were shown as unknown. This could have been due to wrong data entry or wrong data linkage.

Spatial analysis errors were not so apparent as the concepts behind these were not displayed. For instance in creation of bar graph and pie chart for data on annual tax collected by parcel, and the percentage of tax collected by block (figure 16), the formulae or calculations for these were not transparent so it is difficult to predict what sort of errors may have been introduced. There were some errors in the output products especially in the reports. For example, the report on consumers affected due

to sewer reconstruction and expansion (appendix 8) was missing data for some categories. The name of consumers for sewer pipes sew_4_c1 and sew_4_c3 were missing. Colours produced on the plots were not the same as the colours produced on the screen. Hatching patterns for the pie chart and bar graph were not even. Although the colour of the individual elements could be changed, the shading patterns remained the same. The land use map did not have parcel boundaries although these were clearly visible on the screen. Resolution of the screen had to be changed to that of a monochrome before a scanned image of a building could be displayed. Reports produced had to be further edited to give them a pleasing look as some of the records in the reports were extending into the second line. The plots produced for water pipe network could not show the pipe sections and this makes it hard to tell the identity of a pipe without querying it on the screen. The scale of the plots also was too small to enable features to be labelled.

5.5.4 Factors in data usage

The final analyses were based on data that was in most cases improvised. A user not recognising this factor may interpret the information at face value. For instance if information from the pie chart and annual tax bar graph (figure 16) were compared to the city blocks, it would be concluded that the highest percentage of total tax came from KENY01 city block (figure 17). Similarly, the categories selected to map land use by parcels (figure 18) are not the actual existing classes and using this map at face value will lead to a wrong interpretation.

5.6 Conclusion

Possible solutions to prevent or minimise errors would be to verify data input and accuracy at various, stages during the input and correct this before proceeding to the next step. For the study area, verification of attribute data input was done by sorting the attributes by the internal variable and checking that no two features had the same value. Data of different resolutions, different scales, different revision dates should not be mixed and integrated to form one base map without taking into consideration the errors propagated. The nature of data analysis and sources of possible errors in both graphic and attribute data should be identified and minimised if possible. Data sources used should be as current as possible and digitising should be done by one person only, if possible, in order to maintain consistency.

Different disciplines have developed ways of defining and minimising errors that affect their final products. Since GIS data comes from different sources and is used by people from different disciplines, it would be useful to identify each of the sources of errors.

Although an overall error minimising formula is almost impossible to develop for GIS data,¹⁸ factors affecting data accuracy and quality should be identified and users alerted to the reliability of data entered and disseminated from the system.

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CHAPTER SIX

CONCLUSION AND RECOMMENDATIONS

6.1 Conclusion

The purpose of this thesis was to show the applicability of GIS technology to urban management using the multipurpose approach. This has been demonstrated, on a section of the Province of Nairobi, using TIMS an AutoCAD based GIS software. GIS analyses done have shown the capability and efficiency of GIS, in particular TIMS software, to addressing issues within urban areas and include: analysis done on the water network to identify pipes that required urgent work; land uses by parcels mapped to provide planners with information on existing land uses; graph and pie chart produced for tax purposes to enable the administrators evaluate the tax rates; and streets in bad condition identified quickly and also parcels along side major streets affected by road expansion noted. For most of the analyses, reports were produced to show consumers affected. Although these analyses were in most cases done on data that was improvised, the information acquired proves the ability of GIS in helping address infrastructure management problems efficiently. The limitations of GIS technology, especially TIMS software, have been noted and encountered in applying this technology to urban infrastructure management but the analysis have proven the efficiency and suitability of this technology to the task.

The implementation of GIS in developing countries in urban areas has been

proceeding at a very slow rate because of the following factors as discussed in chapter three:^a lack of funds to set up a GIS facility within a municipality; poor data collection techniques; lack of proper coordination among the departments that stand to gain from the installation of GIS; good quality data for both digital and attribute data is almost non-existent; planners and policy makers have not yet appreciated the potential of GIS as a decision making tool; since data for the creation of a database comes from different departments and agencies, rules and specifications of data collection may not be compatible; current software that is introduced in these countries is not easily understood and has been developed for a different environment thus may not address problems that are unique to the area; shortage of qualified people to train and operate GIS; lack of effective institution management within the urban authorities and also across the departments charged with managing the urban areas; education and training facilities for GIS in developing countries have not been fully developed; and GIS is thought of as a process that will replace menial tasks of drafting and data input thus many departments may be reluctant to adopt this technology because of the fact that it may lead to the elimination of certain job categories.

It is difficult to make an estimate of the total cost of setting up a GIS but the

^aFactors affecting the development of GIS in developing countries especially in urban areas are adapted from A. G. -O. Yeh, "The development and applications of geographic information systems for urban and regional planning in the developing countries," and D. A. Hastings and D. M. Clark, "GIS in Africa: problems, challenges and opportunities for co-operation," International Journal of Geographic Information Systems, vol. 5 no.1 (Jan - March 1991) pgs. 5-27, 29-39.

factors that need to be considered include creating an awareness of the technology, identifying the needs of the users, developing an implementation plan that considers the organisational changes required and finally, determining the amount of money required to set up a fully operational GIS.¹ The cost of collecting and converting data and training people in the use of the GIS also needs to be considered when planning the purchase of a GIS.

The selection of a user friendly software based on windows graphic user interface like TIMS will cut the cost of training people to use it and also the ability of the software to link to existing data file systems, will remove the task of re-entering data that in itself is a costly exercise. TIMS software runs on 386 and 486 IBM compatible computers with AutoCAD Release 12 software or higher on personal computers, and on Sun Sparc and IBM RS6000 platforms for a local area network set up. The cost of installing TIMS software on a personal computer will also include the cost of purchasing AutoCAD software where this is not available. Table 45 gives an estimate of the required hardware and software for installing TIMS in 1994.

Table 45. Cost of GIS software and hardware (Canadian Dollars)

AutoCAD software	3,800
TIMS software and Tool Kit	5,616
Digitiser	7,000
Plotter	17,000
Cost of Personal Computer	3,000
Total	36,416

For departments that have in their possession AutoCAD software, the real cost in acquiring a GIS would be in purchasing the TIMS software. The cost of running TIMS on a network will be an additional 350 Canadian dollars for each station. For AutoCAD however, each station requires its own software although a 'floating' licence for one copy may be given that allows users on the network to use the software one at a time.

Policy makers may be reluctant to adopt this expensive technology, however, the overall benefit to the community through increased efficiency in managing the existing resources will in the long run off set the costs of setting up a GIS. Benefits will also be realised through the more efficient way of producing plans, reports and work orders than the with the manual process. The availability of digital data on urban infrastructure will stimulate the development of applications for this data in the private sector. Urban authorities will be able to sell more information, in digital or hard copy, to people that require information on infrastructure layout for economic reasons including engineers, surveyors and private land developers. The establishment of GIS will require infrastructure to support it including access to the software and hardware to be used by the implementers of the system and this indirectly will stimulate the local computer market. Although, the technology will replace the menial tasks of drafting, the people can be retrained in the use of this new technology and drafting boards replaced by workstations.

6.2 Recommendations

Information plays an important role in development and policy makers in developing countries need information on the interactions between people and the effect of set policies on the livelihood of people to enable better planning. One of the problems of sustainable development is the lack of information required for planning and policy making² and as data needs to be collected, it is recommended that this information be integrated into a GIS for more efficient management and analysis..

GIS projects implemented in developing countries are normally to address specific uses often in natural resource and environmental management.³ It is recommended that future GIS projects be geared towards addressing management problems in urban areas. International aid for GIS implementation therefore should be directed to the establishment of GIS facilities for managing urban data for urban areas.

Training in GIS for professional staff involved in managing urban facilities should come before the actual purchase of the GIS components. This will ensure that GIS is developed for specific tasks and problems identified by the users of the system.⁴ It is recommended that people in local authorities be made aware of the potentials and problems of GIS so that decisions on data base designs, software and hardware requirements are taken by the users.

Most departments in local authorities collect their own data suitable for their applications and use.⁵ Since, a multipurpose approach to GIS implementation requires data from different sources be integrated, it is recommended that a common standard for collecting data be developed. In cases where this is impossible, the data accuracy

and quality control measures need to be put in place to minimize errors that are propagated from the sources. For each data set supplied, its quality and accuracy should be noted to alert users to its reliability.

Most features found in urban areas are man made, having regular or discrete boundaries. These features are designed and set out mathematically. Collection and input of this data in a GIS would require that the same type of process used for setting out be employed for a more accurate database. It is recommended that a Computer Assisted Design (CAD) based GIS software be adopted for urban use. Not only will this be a GIS tool but the powerful functions in the CAD package can be used in the design of other physical structures.

Kenya's development plan identifies the need for agencies to work together to address issues affecting the community.⁶ As the capabilities of GIS include being able to integrate data coming from different sources, it is recommended that GIS technology be developed for urban areas to help in identifying issues and as a decision making tool to solving issues affecting the community.

GIS technology alone can not solve the problems of urbanisation but the analysis functions and input/output capability help disseminate information to many users at the same time in an efficient manner to address problem that require immediate response. Present institutional and management policies within local authorities will need to be modified as the hierarchical structure common to many organizations does not allow for easy interactions between the different departments. Hand in hand with developing GIS in urban areas, policies to address organization

structure will need to be implemented to enable the people charged with the responsibility of delivering basic services to the community to operate efficiently. Social economic problems are a major draw back in the development of GIS especially in urban areas where the unemployment rate is on the rise. People opposed to the implementation of GIS may suggest that GIS technology will displace people and thus eliminate job categories. These factors should be weighed against the benefits that will be realised through the more efficient manner of addressing urban infrastructure management issues and as a result create a better environment for all the residents especially the urban poor.

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PM-1 3½"x4" PHOTOGRAPHIC MICROCOPY TARGET
NBS 1010a ANSI/ISO #2 EQUIVALENT

PRECISIONSM RESOLUTION TARGETS

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APPENDICES

APPENDIX 1

REPORT ON DUCTILE IRON WATER PIPES

<u>Pipe no</u>	<u>Pipesize</u>	<u>Sec length</u>
005_S12	290	140.61
005_S02	225	51.29
005_S03	250	108.47
005_S04	160	317.57
005_S05	250	64.29
005_S06	250	31.17
005_S07	270	103.90
005_S08	360	32.48
005_S09	250	11.83
005_S10	350	13.26
005_S11	240	39.74
005_S15	310	34.40
005_S16	300	47.72
005_S17	300	38.97
005_S18	310	146.41
005_S18	310	146.41
005_S01	225	317.32
005_S28	190	7.01
005_S29	280	79.89
005_S30	270	61.06
005_S32	200	59.44
005_S34	260	110.13
005_S35	290	96.33
006_S16	360	121.43
013_C5	55	72.27
006_S2	180	373.09
006_S3	180	62.30
006_S4	270	87.85
006_S5	260	30.32

APPENDIX 2

REPORT ON PIPES OF SIZE 100 TO 400 MM

<u>Piperef</u>	<u>Size(mm)</u>	<u>Type</u>	<u>Length(m)</u>
001_S01	280	PVC	7.11
001_S02	300	PVC	38.96
001_S03	300	PVC	22.20
001_S04	300	PVC	7.37
001_S05	350	PVC	59.52
001_S06	250	PVC	11.92
001_S07	280	PVC	21.60
001_S08	280	PVC	29.34
001_S09	350	PVC	50.88
001_S10	250	PVC	44.55
001_S10	250	PVC	44.55
002_S01	300	PVC	6.39
002_S02	300	PVC	51.22
002_S03	300	PVC	41.86
002_S04	260	PVC	41.44
003_S02	250	PVC	371.10
003_S03	280	PVC	139.54
003_S04	300	PVC	28.32
003_S05	290	PVC	30.70
003_S06	300	PVC	49.68
003_S07	300	PVC	101.75
003_S08	300	PVC	115.77
003_S09	300	PVC	67.71
003_S09	300	PVC	67.71
003_S10	300	PVC	29.43
003_S11	290	PVC	104.68
004_S01	290	PVC	184.67
004_S02	250	PVC	170.94
004_S03	250	PVC	56.75
004_S03	250	PVC	56.75
004_S04	280	PVC	172.10
004_S05	240	PVC	17.98
004_S06	260	PVC	111.22
004_S07	280	PVC	31.40
005_S01	225	DUC. IRON	317.32
005_S02	225	DUC. IRON	51.29
005_S03	250	DUC. IRON	108.47
005_S04	160	DUC. IRON	317.57
005_S05	250	DUC. IRON	64.29
005_S06	250	DUC. IRON	31.17
005_S07	270	DUC. IRON	103.90
005_S08	360	DUC. IRON	82.48
005_S09	250	DUC. IRON	81.83
005_S10	350	DUC. IRON	103.26
005_S12	290	DUC. IRON	140.61
005_S13	250	PVC	41.86

APPENDIX 2 CONTINUED

REPORT ON PIPES OF SIZE 100 TO 400 MM

<u>Piperef</u>	<u>Size(mm)</u>	<u>Type</u>	<u>Length(m)</u>
005_S14	260	PVC	105.68
005_S15	310	DUC. IRON	34.40
005_S16	300	DUC. IRON	47.72
005_S17	300	DUC. IRON	38.97
005_S18	310	DUC. IRON	146.41
005_S18	310	DUC. IRON	146.41
005_S28	190	DUC. IRON	7.01
005_S29	280	DUC. IRON	79.89
005_S30	270	DUC. IRON	61.06
005_S31	240	PVC	44.81
005_S32	200	DUC. IRON	59.44
005_S33	360	PVC	83.93
005_S34	260	DUC. IRON	110.13
005_S35	290	DUC. IRON	96.33
005_S36	350	DUC. IRON	79.00
006_S10	270	DUC. IRON	75.47
006_S11	270	DUC. IRON	85.47
006_S12	320	DUC. IRON	230.08
006_S13	260	PVC	49.66
006_S14	240	PVC	216.39
006_S15	230	PVC	136.14
006_S16	360	DUC. IRON	121.43
006_S17	360	PVC	45.66
006_S18	364	PVC	18.81
006_S19	340	PVC	37.84
006_S2	180	DUC. IRON	373.09
006_S20	360	PVC	24.85
006_S21	250	PVC	5.38
006_S22	350	DUC. IRON	35.60
006_S23	360	DUC. IRON	51.96
006_S24	244	PVC	6.46
006_S25	240	PVC	14.80
006_S26	260	PVC	20.80
006_S27	220	PVC	11.89
006_S28	220	PVC	11.82
006_S29	280	DUC. IRON	8.11
006_S3	180	DUC. IRON	62.30
006_S30	220	PVC	7.21
006_S4	270	DUC. IRON	87.85
006_S5	260	DUC. IRON	30.32
006_S6	360	DUC. IRON	33.46
006_S7	360	DUC. IRON	37.98
006_S8	320	DUC. IRON	36.40
006_S9	310	DUC. IRON	24.88
007_C1	150	PE	7.89
007_S10	300	PVC	116.76

APPENDIX 2 CONTINUED

REPORT ON PIPES OF SIZE 100 TO 400 MM

<u>Piperef</u>	<u>Size(mm)</u>	<u>Type</u>	<u>Length(m)</u>
007_S11	200	PVC	51.28
007_S12	230	PVC	69.02
007_S13	230	PVC	54.13
007_S14	270	PVC	93.25
007_S16	240	PVC	45.50
007_S17	290	DUC. IRON	43.49
007_S2	150	DUC. IRON	40.22
007_S3	200	PVC	167.14
007_S4	270	PVC	81.73
007_S5	260	PVC	83.25
007_S6	250	PVC	87.33
007_S7	350	PVC	32.24
007_S8	290	PVC	96.36
007_S9	350	DUC. IRON	65.99
008_S1	190	PVC	144.60
008_S10	270	PVC	41.56
008_S2	175	PVC	62.53
008_S3	250	PVC	80.07
008_S4	300	PVC	503.01
008_S5	200	PVC	70.56
008_S6	270	PVC	85.83
008_S7	230	PVC	97.50
008_S8	230	PVC	52.29
008_S9	250	PVC	25.52
009_S1	270	DUC. IRON	259.55
009_S10	280	DUC. IRON	328.37
009_S11	240	PVC	124.43
009_S2	150	DUC. IRON	67.79
009_S3	270	DUC. IRON	20.64
009_S4	310	PVC	58.13
009_S5	250	PVC	53.21
009_S6	350	DUC. IRON	19.22
009_S7	290	DUC. IRON	18.68
009_S8	270	PVC	108.87
009_S9	310	PVC	129.24
010_S1	350	PVC	575.81
010_S1	350	PVC	575.81
010_S10	250	PVC	171.98
010_S11	350	PVC	74.84
010_S2	350	PVC	60.47
010_S3	350	PVC	76.58
010_S4	350	DUC. IRON	21.61
010_S5	350	DUC. IRON	63.22
010_S6	260	DUC. IRON	49.08
010_S7	190	PVC	57.89
010_S8	250	PVC	45.78

APPENDIX 2 CONTINUED

REPORT ON PIPES OF SIZE 100 TO 400 MM

<u>Piperef</u>	<u>Size (mm)</u>	<u>Type</u>	<u>Length(m)</u>
010_S9	200	DUC. IRON	55.09
011_S1	300	PVC	25.07
011_S10	350	DUC. IRON	149.29
011_S11	250	PVC	51.83
011_S11	250	PVC	51.83
011_S12	350	PVC	148.79
011_S13	260	PVC	31.88
011_S14	250	DUC. IRON	19.00
011_S15	350	PVC	20.98
011_S16	340	PVC	41.21
011_S17	250	PVC	154.46
011_S18	280	PVC	226.52
011_S19	300	DUC. IRON	157.97
011_S2	300	PVC	69.71
011_S20	300	DUC. IRON	131.12
011_S21	340	DUC. IRON	82.07
011_S22	280	DUC. IRON	30.66
011_S3	300	PVC	54.75
011_S4	290	PVC	94.01
011_S5	300	PVC	92.43
011_S6	300	PVC	36.29
011_S7	260	PVC	66.69
011_S8	250	PVC	24.80
011_S9	200	DUC. IRON	34.72
012_S1	250	PVC	41.01
012_S2	260	PVC	49.52
012_S3	260	PVC	24.40
012_S4	300	PVC	33.94
012_S5	300	PVC	51.30
012_S6	300	PVC	20.57
012_S7	200	PVC	45.81
012_S8	300	PVC	34.79
012_S8	300	PVC	34.79
013_C2	350	PVC	25.04
013_S1	250	DUC. IRON	7.26
013_S1	250	DUC. IRON	7.26
013_S2	250	PVC	49.80
013_S3	250	PVC	18.06
013_S4	240	PVC	32.25
013_S5	250	DUC. IRON	29.24
013_S6	350	PVC	27.83
013_S7	260	PVC	40.1
013_S8	260	PVC	36.34
014_S1	240	PVC	50.61
014_S10	290	PVC	63.25
014_S2	260	PVC	38.56

APPENDIX 2 CONTINUED

REPORT ON PIPES OF SIZE 100 TO 400 MM

<u>Piperef</u>	<u>Size(mm)</u>	<u>Type</u>	<u>Length(m)</u>
014_S3	270	PVC	31.71
014_S4	290	DUC. IRON	7.96
014_S5	290	DUC. IRON	10.40
014_S6	290	PVC	31.66
014_S7	350	PVC	29.59
014_S8	350	DUC. IRON	6.90
014_S9	350	PVC	27.17

APPENDIX 3

REPORT ON PIPES LAID BEFORE JANUARY 1950

<u>Piperef</u>	<u>Size(mm)</u>	<u>Type</u>	<u>Length(m)</u>
003_S03	280	PVC	139.54
003_S04	300	PVC	28.32
003_S05	290	PVC	30.70
003_S06	300	PVC	49.68
003_S07	300	PVC	101.75
003_S08	300	PVC	115.77
003_S09	300	PVC	67.71
003_S09	300	PVC	67.71
003_S10	300	PVC	29.43
003_S11	290	PVC	104.68
004_C01	50	COPPER	111.82
004_C02	75	COPPER	15.92
004_C03	50	COPPER	42.27
004_C04	55	COPPER	41.25
004_C05	60	COPPER	20.98
004_C06	95	COPPER	50.96
004_S01	290	PVC	184.67
004_S02	250	PVC	170.94
004_S03	250	PVC	56.75
004_S03	250	PVC	56.75
004_S04	280	PVC	172.10
004_S05	240	PVC	17.98
004_S06	260	PVC	111.22
004_S07	280	PVC	31.40
005_S12	290	DUC. IRON	140.61
006_C1	30	COPPER	58.36
006_C1	30	COPPER	58.36
006_C10	15	COPPER	57.77
006_C11	15	COPPER	29.54
006_C12	15	COPPER	38.29
006_C13	15	COPPER	6.83
006_C14	25	COPPER	18.63
006_C15	25	COPPER	15.74
006_C16	25	COPPER	20.14
006_C17	60	COPPER	32.94
006_C18	75	COPPER	25.13
006_C19	60	COPPER	44.06
006_C2	35	COPPER	35.65
006_C20	60	COPPER	22.45
006_C21	50	COPPER	17.53
006_C22	25	COPPER	46.26
006_C23	55	COPPER	19.89
006_C24	40	COPPER	39.76
006_C25	65	COPPER	33.09
006_C26	55	COPPER	38.06
006_C27	65	COPPER	41.80

APPENDIX 3 CONTINUED

REPORT SHOWING PIPES LAID BEFORE JANUARY 1950

<u>Piperef</u>	<u>Size(mm)</u>	<u>Type</u>	<u>Length(m)</u>
006_C28	45	COPPER	71.10
006_C3	15	COPPER	21.82
006_C4	15	COPPER	13.47
006_C5	15	COPPER	12.34
006_C6	80	COPPER	20.92
006_C7	15	COPPER	8.34
006_C8	30	COPPER	10.36
006_C9	35	COPPER	55.30
006_S1	550	HYPRESS CO	624.10
006_S10	270	DUC. IRON	75.47
006_S11	270	DUC. IRON	85.47
006_S12	320	DUC. IRON	230.08
006_S13	260	PVC	49.66
006_S14	240	PVC	216.39
006_S15	230	PVC	136.14
006_S16	360	DUC. IRON	121.43
006_S17	360	PVC	45.66
006_S18	364	PVC	18.81
006_S19	340	PVC	37.84
006_S2	180	DUC. IRON	373.09
006_S20	360	PVC	24.85
006_S21	250	PVC	5.38
006_S22	350	DUC. IRON	35.60
006_S23	360	DUC. IRON	51.96
006_S24	244	PVC	6.46
006_S25	240	PVC	14.80
006_S26	260	PVC	20.80
006_S27	220	PVC	11.89
006_S28	220	PVC	11.82
006_S29	280	DUC. IRON	8.11
006_S3	180	DUC. IRON	62.30
006_S30	220	PVC	7.21
006_S4	270	DUC. IRON	87.85
006_S5	260	DUC. IRON	30.32
006_S6	360	DUC. IRON	33.46
006_S7	360	DUC. IRON	37.98
006_S8	320	DUC. IRON	36.40
006_S9	310	DUC. IRON	24.88
007_C1	150	PE	7.89
007_C10	20	COPPER	48.56
007_C11	20	COPPER	29.26
007_C12	20	COPPER	25.58
007_C13	20	COPPER	17.87
007_C14	15	COPPER	37.12
007_C2	65	COPPER	6.81
007_C3	15	COPPER	22.34

APPENDIX 3 CONTINUED

REPORT SHOWING PIPES LAID BEFORE JANUARY 1950

<u>Piperef</u>	<u>Size (mm)</u>	<u>Type</u>	<u>Length (m)</u>
007_C4	15	COPPER	21.61
007_C5	65	COPPER	21.58
007_C6	35	COPPER	53.54
007_C7	25	COPPER	17.70
007_C8	20	COPPER	13.93
007_C9	20	COPPER	39.60
007_S1	550	HYPRESS CO	173.70
007_S10	300	PVC	116.76
007_S11	200	PVC	51.28
007_S12	230	PVC	69.02
007_S13	230	PVC	54.13
007_S14	270	PVC	93.25
007_S15	20	COPPER	21.27
007_S15	20	COPPER	21.27
007_S16	240	PVC	45.50
007_S17	290	DUC. IRON	43.49
007_S2	150	DUC. IRON	40.22
007_S3	200	PVC	167.14
007_S4	270	PVC	81.73
007_S5	260	PVC	83.25
007_S6	250	PVC	87.33
007_S7	350	PVC	32.24
007_S8	290	PVC	96.36
007_S9	350	DUC. IRON	65.99
010_C1	80	COPPER	22.13
010_C2	80	COPPER	107.03
010_C3	35	COPPER	102.20
010_C4	95	COPPER	20.22
010_C5	35	COPPER	49.78
010_C6	35	COPPER	33.31
010_C7	60	COPPER	12.34
010_C8	15	COPPER	16.16
010_S1	350	PVC	575.81
010_S10	250	PVC	171.98
010_S11	350	PVC	74.84
010_S2	350	PVC	60.47
010_S3	350	PVC	76.58
010_S4	350	DUC. IRON	21.61
010_S5	350	DUC. IRON	63.22
010_S6	260	DUC. IRON	49.08
010_S7	190	PVC	57.89
010_S8	250	PVC	45.78
010_S9	200	DUC. IRON	55.09
011_C1	55	COPPER	39.39
011_C10	80	COPPER	49.27
011_C11	85	COPPER	44.56

APPENDIX 3 CONTINUED

REPORT SHOWING PIPES LAID BEFORE JANUARY 1950

<u>Piperef</u>	<u>Size(mm)</u>	<u>Type</u>	<u>Length(m)</u>
011_C12	25	COPPER	77.82
011_C13	20	COPPER	43.27
011_C14	30	COPPER	29.75
011_C15	20	COPPER	40.75
011_C16	25	COPPER	30.82
011_C17	25	COPPER	57.38
011_C18	20	COPPER	75.39
011_C19	35	COPPER	127.03
011_C2	60	COPPER	46.60
011_C20	45	COPPER	58.92
011_C21	40	COPPER	52.87
011_C22	45	COPPER	37.76
011_C3	60	COPPER	25.00
011_C4	35	COPPER	51.91
011_C5	95	COPPER	23.28
011_C6	90	COPPER	60.88
011_C7	85	COPPER	141.23
011_C8	85	COPPER	35.03
011_C9	80	COPPER	44.42
011_S1	300	PVC	25.07
011_S10	350	DUC. IRON	149.29
011_S11	250	PVC	51.83
011_S11	250	PVC	51.83
011_S12	350	PVC	148.79
011_S13	260	PVC	31.88
011_S14	250	DUC. IRON	19.00
011_S15	350	PVC	20.98
011_S16	340	PVC	41.21
011_S17	250	PVC	154.46
011_S18	280	PVC	226.52
011_S19	300	DUC. IRON	157.97
011_S2	300	PVC	69.71
011_S20	300	DUC. IRON	131.12
011_S21	340	DUC. IRON	82.07
011_S22	280	DUC. IRON	30.66
011_S3	300	PVC	54.75
011_S4	290	PVC	94.01
011_S5	300	PVC	92.43
011_S6	300	PVC	36.29
011_S7	260	PVC	66.69
011_S8	250	PVC	24.80
011_S9	200	DUC. IRON	34.72
012_C1	20	COPPER	54.77
012_C2	20	COPPER	28.90
012_C3	30	COPPER	42.73
012_C4	25	COPPER	38.25

APPENDIX 3 CONTINUED

REPORT SHOWING PIPES LAID BEFORE JANUARY 1950

<u>Piperef</u>	<u>Size (mm)</u>	<u>Type</u>	<u>Length (m)</u>
012_C5	15	COPPER	69.63
012_C6	30	COPPER	28.69
012_C7	30	COPPER	23.12
012_S1	250	PVC	41.01
012_S2	260	PVC	49.52
012_S3	260	PVC	24.40
012_S4	300	PVC	33.94
012_S5	300	PVC	51.30
012_S6	300	PVC	20.57
012_S7	200	PVC	45.81
012_S8	300	PVC	34.79
012_S8	300	PVC	34.79
013_C1	30	COPPER	40.53
013_C2	350	PVC	25.04
013_C3	30	COPPER	31.90
013_C4	55	COPPER	48.03
013_C5	55	DUC. IRON	72.27
013_C6	25	COPPER	61.91
013_C7	55	COPPER	25.04
013_C8	35	COPPER	56.61
013_C9	45	COPPER	21.11
013_S1	250	DUC. IRON	7.26
013_S1	250	DUC. IRON	7.26
013_S2	250	PVC	49.80
013_S3	250	PVC	18.06
013_S4	240	PVC	32.25
013_S5	250	DUC. IRON	29.24
013_S6	350	PVC	27.83
013_S7	260	PVC	40.10
013_S8	260	PVC	36.34
014_C1	75	COPPER	58.83
014_C10	25	COPPER	36.87
014_C2	65	COPPER	25.20
014_C3	25	COPPER	81.54
014_C4	25	COPPER	89.75
014_C5	25	COPPER	29.46
014_C6	25	COPPER	55.81
014_C7	65	COPPER	40.94
014_C8	65	COPPER	38.20
014_C9	25	COPPER	80.83
014_S1	240	PVC	50.61
014_S10	290	PVC	63.25
014_S2	260	PVC	38.56
014_S3	270	PVC	31.71
014_S4	290	DUC. IRON	7.96
014_S5	290	DUC. IRON	10.40

APPENDIX 3 CONTINUED

REPORT SHOWING PIPES LAID BEFORE JANUARY 1950

<u>Piperef</u>	<u>Size (mm)</u>	<u>Type</u>	<u>Length (m)</u>
014_S6	290	PVC	31.66
014_S7	350	PVC	29.59
014_S8	350	DUC. IRON	6.90
014_S9	350	PVC	27.17

APPENDIX 4

PIPES TO BE REPLACED

<u>Pipe ref</u>	<u>Size</u>	<u>Type</u>	<u>Length</u>	<u>From ele</u>	<u>To ele</u>
005_S02	225	DUC. IRON	51.29		
005_S03	250	DUC. IRON	108.47		
005_S04	160	DUC. IRON	317.57		
005_S05	250	DUC. IRON	64.29		
005_S06	250	DUC. IRON	31.17		
005_S07	270	DUC. IRON	103.90		
005_S08	360	DUC. IRON	82.48		
005_S09	250	DUC. IRON	81.83		
005_S10	350	DUC. IRON	103.26		
005_S11	240	DUC. IRON	39.74		
005_S15	310	DUC. IRON	34.40		
005_S16	300	DUC. IRON	47.72		
005_S17	300	DUC. IRON	38.97		
005_S18	310	DUC. IRON	146.41		
005_S18	310	DUC. IRON	146.41		
005_S01	225	DUC. IRON	317.32		
005_S28	190	DUC. IRON	7.01		
005_S29	280	DUC. IRON	79.89		
005_S30	270	DUC. IRON	61.06		
005_S32	200	DUC. IRON	59.44		
005_S34	260	DUC. IRON	110.13		
005_S35	290	DUC. IRON	96.33		
009_S1	270	DUC. IRON	259.55		
009_S2	150	DUC. IRON	67.79		
009_S3	270	DUC. IRON	20.64		
009_S6	350	DUC. IRON	19.22		
009_S7	290	DUC. IRON	18.68		
009_S10	280	DUC. IRON	328.37		
005_S36	350	DUC. IRON	79.00		

APPENDIX 5

MANHOLES INVOLVED IN PROJECT

<u>Manref</u>	<u>Type</u>	<u>Depth(m)</u>	<u>X</u>	<u>Y</u>
MAN_5	CPB	1.1	255914.54	9858529.50
MAN_6	PSB	1.0	255048.98	9858065.58
MAN_9	CPB	1.0	255082.60	9857548.93
MAN_10	PSM	1.5	255658.05	9857961.94
MAN_12	PSM	1.6	256957.30	9857987.38
MAN_13	PSM	2.1	256995.53	9857950.95
MAN_14	PSM	2.0	256431.94	9857682.85
MAN_15	PSM	2.1	256218.02	9857683.05

CONSUMERS AFFECTED BY PROJECT

<u>Bldg</u>	<u>Consumer</u>	<u>Boxno</u>	<u>Street</u>
20	JULINA NAKHUMICHA	1714	State House Road
32	HELEN STOIKA	357	State House Road
33	JAMES WAMWATI	314	State House Road
34	JERRY NYANGE	293	State House Road
35	KENNETH KAMAU PATE	284	State House Road
36	MOMMUR LENTALE	547	State House Road
37	AHMED SONKULE	574	State House Road
42	JANE WANJAL	931	Nyerere Road
43	WAMBUI BURASA	1013	State House Road
44	PAMELA BARASA DEL	300	State House Road
45	NUMULI DELMONDA	295	State House Road
46	FURULI KAMFUNDI	425	State House Road
47	GUTUIL HENDRACK	1018	State House Road
49	FERUBI KASULE	361	Denis Prit Road
50	KANINI MAPANGALA	348	Denis Prit Road
51	DELMOT SAMBALA	468	Denis Prit Road
52	PRAXY HULIVA	395	Denis Prit Road
53	MERCY MUSTESHI	298	Denis Prit Road
54	CONSTANCE KEHANJA	345	Denis Prit Road
55	FERRY KIMIP'RI	296	State House Road
56	PERRY WACEKE KAM	592	State Hse Ave
57	EVELYN KAMAU	261	State House Road
58	EVELY FURAKA	275	Ralph Bunge Road
81	WAINIAINA ORASI	831	Milimani Road
86	KENYAT HENRIETA	337	Milimani Lane
87	MIGUI KAMAU	343	State Hse Ave
89	SAMBA WASWA	275	Wato Lane
91	BONGOMAN NELIMA	356	Valley Road
92	RESINTA NAKHANU	350	Valley Road
94	SYLVESTER MASOME	504	Milimani Road
96	CAROLE OPONDO	335	Ralph Bunge Road

CONSUMERS AFFECTED BY PROJECT CONTINUED

<u>Bldg</u>	<u>Consumer</u>	<u>Boxno</u>	<u>Street</u>
97	IBRAHIM APOLO	254	Milimani Road
103	DENNIS MURUGI	620	Lenana Road
105	KAMAU WAFULA	798	Isebania Road
107	MOHAMMED ISHMAEL	1351	Arwings Kodhek Roa

APPENDIX 6

REPORT ON AFFECTED CONSUMERS

<u>Consumer</u>	<u>Boxno</u>	<u>Meter</u>	<u>Bldg</u>	<u>Amnt</u>	<u>Bill</u>
PAMELA BARASA DEL	300	MET_35	44	1100.16	55.01
PAMELA BARASA DEL	300	MET_36	44	1063.49	53.17
WAMBUI BURASA	1013	MET_33	43	1164.88	58.24
GUTUIL HENDRACK	1018	MET_50	47	790.87	39.54
KENYAT HENRIETA	337	MET_38	86	876.23	43.81
PRAXY HULIVA	395	MET_45	52	318.53	15.93
MOHAMMED ISHMAEL	1351	MET_74	107	527.53	26.38
MIGUI KAMAU	343	MET_39	87	796.13	39.81
EVELYN KAMAU	261	MET_40	57	689.35	34.47
EVELYN KAMAU	261	MET_41	57	656.61	32.83
KENNETH KAMAUPATE	284	MET_52	35	911.61	45.58
KENNETH KAMAUPATE	284	MET_53	35	923.33	46.17
FURULI KAMFUNDI	425	MET_37	46	965.14	48.26
FERUBI KASULE	361	MET_48	49	46.57	2.33
CONSTANCE KEHANJA	345	MET_43	54	465.18	23.26
MOMMUR LENTALE	547	MET_51	36	800.64	40.03
KANINI MAPANGALA	348	MET_47	50	117.86	5.89
DENNIS MURUGI	620	MET_148	103	82.46	4.12
MERCY MUSTESHI	298	MET_44	53	401.19	20.06
RESINTA NAKHANU	350	MET_72	92	849.67	42.48
JULINA NAKHUMICHA	1714	MET_30	20	1638.69	81.93
JULINA NAKHUMICHA	1714	MET_31	20	1586.63	79.33
BONGOMAN NELIMA	356	MET_71	91	919.98	46.00
CAROLE OPONDO	335	MET_73	96	768.84	38.44
DELMOT SAMBALA	468	MET_46	51	218.74	10.94
AHMED SONKULE	574	MET_49	37	705.87	35.29
PERRY WACEKE KAM	592	MET_42	56	569.84	28.49
KAMAU WAFULA	798	MET_75	105	195.20	9.76
JAMES WAMWATI	314	MET_54	33	929.76	46.49
JAMES WAMWATI	314	MET_55	33	941.51	47.08
JANE WANJAL	931	MET_32	42	1486.86	74.34
SAMBA WASWA	275	MET_149	89	966.86	48.34
TOTAL (Ksh)				24476.20	1223.80

APPENDIX 7

CONSUMERS AFFECTED BY SEWER RECONSTRUCTION AND EXPANSION

<u>Sewref</u>	<u>Bldg</u>	<u>Owner</u>	<u>Boxno</u>	<u>Length</u>	<u>Size</u>	<u>Cost</u>
SEW_11_C10	16	LEPOA KINUTHIA	1133	43.50	15	783000.00
SEW_11_C6	15	KAMAU KARANJA	455	48.34	15	870120.00
SEW_12_C1	22	MARSE SACCOH	297	25.98	15	467640.00
SEW_12_C4	26	HEPPER NYOGES	329	30.13	16	578496.00
SEW_13_C5	6	PETER ORINDA	383	25.81	15	464580.00
SEW_2_C5	90	KANDA WAFULA	245	19.53	15	351540.00
SEW_4_C1	196		1284	22.46	15	404280.00
SEW_4_C2	194	NAKHANU NASIMIYU	289	19.74	15	355320.00
SEW_4_C3	196		1284	69.34	15	1248120.00
SEW_5_C1	175	MUDAVA ASILEMUSI	302	58.83	15	1058940.00
SEW_5_C2	181	PAUL KUMENDA	265	29.80	15	536400.00
SEW_5_C3	174	MOHAMMED OUKE	345	42.00	15	756000.00
SEW_7_C3	128	JODY RESINTA	900	18.25	15	328500.00
SEW_7_C4	135	AKBAR ALLAM	473	51.03	15	918540.00
SEW_8_C16	68	GIDEON KAMAU	275	64.34	15	1158120.00
SEW_8_C2	88	MACHOKA WASIKE	537	44.92	15	808560.00
SEW_8_C3	80	KAMAU ORIDO	376	24.60	15	442800.00
SEW_8_C4	89	SAMBA WASWA	275	43.19	15	777420.00
SEW_8_C5	79	ORONI OTANI	339	21.84	15	393120.00
SEW_9_C1	43	WAMBUI BURASA	1013	43.24	15	778320.00
SEW_9_C15	56	PERRY WACEKE KAM	592	72.90	15	1312200.00
SEW_9_C3	45	NUMULI DELMONDA	295	65.76	15	1183680.00

TOTAL COST (Ksh) 15975696.00

APPENDIX 8

PARCELS CLOSE TO OVERFLOWING MANHOLES

<u>Lot no</u>	<u>Owner</u>	<u>Address</u>	<u>Req no</u>
107	MOHAMMED ISHMAEL	1351	KILI001106
129	CHARLES HOCSTABLE	519	KILI003003
130	SHAH KUMAR	245	KILI003004
131	SHAH ABDALA	233	KILI003005
132	PATEL MOMMAR	259	KILI003006
133	SULEIMAN AZIZ	248	KILI003007
171	SUDI KABULA	343	KILI003045
172	SUDI KABULA	356	KILI003046
176	FURERIA FORD	1312	KILI003050
177	FURERIA FORD	325	KILI003051
178	FURERIA FORD	330	KILI003052
183	CHARLES TOTEMI	367	KILI003057
189	CHARLES ROSTOM	507	KILI003063
192	CHARLES EL SHAYAL	496	KILI003066
195	MULEMEB MUMUELA	490	KILI003069
203	WAMBUI WANJIRU	373	KENY001052
204	NEKESA NANJALA	672	KENY001001

APPENDIX 9

PARCELS AFFECTED BY ROAD WIDENING

<u>Lotno</u>	<u>Regno</u>	<u>Areataken</u>	<u>Owner</u>	<u>Address</u>	<u>Compensation</u>
41	KILI001041	9819.59	KILEND WAFULA	1783	235670160.00
42	KILI001042	3070.89	JANE WANJAL	931	73701360.00
49	KILI001049	1228.83	FERUBI KASULE	361	29491920.00
50	KILI001050	957.66	KANINI MAPANGALA	348	22983840.00
51	KILI001051	1682.19	DELMOT SAMBALA	468	40372560.00
52	KILI001052	1155.74	PRAXY HULIVA	395	27737760.00
53	KILI001053	581.24	MERCY MUSTESHI	298	13949760.00
54	KILI001054	1255.69	CONSTAN KEHANJA	345	30136560.00
55	KILI001055	737.28	FERRY KIMIRIRI	296	17694720.00
56	KILI001056	1835.70	PERRYWACEKE KAM	592	44056800.00
66	KILI001066	897.67	ISSA WAMWARA	497	21544080.00
67	KILI001067	358.17	TINA WAMBUI	265	8596080.00
69	KILI001069	347.70	DESMOND GARBAER	296	8344800.00
71	KILI001071	31.69	TIM SOUTTER	636	760560.00
81	KILI001080	1413.83	WAINIAINA ORASI	831	33931920.00
88	KILI001087	2962.96	MACHOKA WASIKE	537	71111040.00
90	KILI001089	1401.79	KANDA WAFULA	245	33642960.00
91	KILI001090	1489.33	BONGOMAN NELIMA	356	35743920.00
92	KILI001091	1464.43	RESINTA NAKHANU	350	35146320.00

Total Compensation(ksh)					744966000.00

APPENDIX 10

STREETS IN BAD CONDITION

<u>str no</u>	<u>name</u>	<u>length</u>	<u>lane</u>	<u>cost</u>
0001_003	UHURU	762.29	6	68606100.00
0001_004	UHURU	871.12	6	78400800.00
0001_005	UHURU	608.19	6	54737100.00
0001_006	UHURU	2360.32	6	212428800.00
0003_003	VALLEY	144.36	6	12992400.00
0003_004	VALLEY	150.08	6	13507200.00
0003_005	VALLEY	293.09	6	26378100.00
0003_006	VALLEY	303.21	6	27288900.00
0004_001	MBAGATHI	1088.89	6	98000100.00
0005_0013	NGONG RD	389.55	2	11686500.00
0005_004	NGONG	167.92	4	10075200.00
0006_002	HAILESELLA	63.40	4	3804000.00
0006_003	HAILESELLA	226.38	4	13582800.00
0006_004	HAILESELLA	94.69	4	5681400.00
0007_003	STATE HOUS	175.73	2	5271900.00
0007_004	STATE HOUS	98.37	2	2951100.00
0007_005	STATE HOUS	295.99	2	8879700.00
0007_009	STATE HOUS	198.94	2	5968200.00
0009_001	RALPH BUNG	102.74	2	3082200.00
0009_002	RALPH BUNG	250.52	2	7515600.00
0009_009	RALPH BUNG	98.00	2	2940000.00
0010_003	BISHOPS	117.47	2	3524100.00
0010_006	BISHOPS	146.14	2	4384200.00
0012_002	MAMLAKA	139.99	2	4199700.00
0012_003	MAMLAKA	558.03	2	16740900.00
0012_004	MAMLAKA	114.56	2	3436800.00
0015_006	MARA	256.00	2	7680000.00
0016_001	UPPER HILL	381.99	2	11459700.00
0016_002	UPPER HILL	377.68	2	11330400.00
0016_003	UPPER HILL	290.06	2	8701800.00
0016_004	UPPER HILL	112.81	2	3384300.00
0016_005	UPPER HILL	149.64	2	4489200.00
0025_002	FIFTH NGON	131.03	2	3930900.00
0026_001	MBAGATHI	575.33	2	17259900.00
0026_002	MBAGATHI	649.86	2	19495800.00
0033_001	RAGATI	176.74	2	5302200.00
0043_000	MAMLAKA	306.39	2	9191700.00
0044_001	KIVEMIA	105.54	2	3166200.00
0044_002	KIVEMIA	86.67	2	2600100.00
0044_003	KIVEMIA	94.34	2	2830200.00
0046_000	UPPER HILL	302.60	1	4539000.00
0047_003	ARWINGS KO	215.11	2	6453300.00
0047_004	ARWINGS KO	181.44	2	5443200.00
0048_002	LENANA	537.70	2	16131000.00
0049_000	ISEBANIA	505.41	2	15162300.00
0050_002	WOODLANDS	145.09	2	4352700.00

APPENDIX 10 CONTINUED

STREETS IN BAD CONDITION

<u>str no</u>	<u>name</u>	<u>length</u>	<u>lane</u>	<u>cost</u>
0050_003	WOODLANDS	65.48	2	1964400.00
0052_000	DOROBO	496.55	2	14896500.00
0054_000	WATO	330.39	2	9911700.00
0056_001	DENIS PRIT	278.27	2	8348100.00
0056_002	DENIS PRIT	187.48	2	5624400.00
0057_001	LANGATA RD	1378.00	2	41340000.00
0057_002	LANGATA RD	1095.00	2	32850000.00
0057_003	LANGATA RD	1589.68	3	71535600.00

Approx. cost				1055438400.00

APPENDIX 11

**BUILDINGS VALUED BETWEEN 700,000 (C\$14,000) AND
1,000,000 (C\$20,000) KENYA SHILLINGS**

<u>bd_id</u>	<u>pin</u>	<u>owner</u>	<u>address</u>	<u>annualrent</u>
66	KILI001066	WAMWARA ISSA	497	4143.93
94	KILI001093	MASOME SYLVESTER	504	4834.70
52	KILI001052	HULIVA PRAXY	395	3733.27
46	KILI001046	KAMFUNDI FURULI	425	3603.63
19	KILI001019	NELIMA NAK HERIME	464	4749.30
17	KILI001017	WESONGA FRANCIS	499	4351.24
15	KILI001015	KARANJA KAMAU	455	3946.75
23	KILI001023	MULI NOME	388	3529.22
122	KILI002011	SAKAWA LAWRENCE	474	4783.29
126	KILI003001	ASALAM DUBIGA	410	4206.39
134	KILI003008	YUSUF ABDALLA	402	3602.75

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