Introducing GIS and Multi-criteria analysis in road path planning process in Nigeria
A case study of Lokoja, Kogi State

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Abstract

In planning a suitable road network, planners put into consideration factors like gradients or slope of the area, available land-use and soil type, community or national landmarks and governmental interest. These different considerations and interest make the planning process complex and as such there might be confusion of interest in the decision making. The use of GIS and Multi-criteria analysis has helped planners to achieve desired and more accurate results and as such reducing the complex nature in the planning process allowing different stakeholders to reach a general conclusion.

Multi-criteria analysis (MCA) prevents the imposition of limit on the form of criteria and gives opportunity to decision makers to enter their own judgments. This provides a better communication among the decision makers and the entire community and as such creating a more open choice for analysis and possible changes if necessary. The aim of this thesis is to introduce the possibility of using GIS and MCA in road path planning in Nigeria, using Lokoja, the capital of Kogi state as a case study.

In actualizing the aim, satellite images of the area of study was obtained from the Landsat home page and analyzed to derive the land-use map. The land-use over the area of study was classified into five different classes using the unsupervised method of classification. A DEM over the area of study was downloaded from the website of the Consortium of Spatial information (CSI) and the DEM was used to derive the slope map over the area of study and the analytic hierarchy process (AHP) method was used in weighting the criterions according to preference.

As the conclusion of the analysis, a road path between two points was obtained. The start point of the road was located on an approximate coordinate of 219002, 958986 meters and the destination point on an approximate coordinate of 320322, 878101 meters. The start and destination point were selected randomly without any pre-knowledge of the area. The thesis has succeeded in showing that it is possible to determine a road path between two points using Geographic information system (GIS) and Multi-criteria analysis in Nigeria.

**Keywords:** Geographic information systems, Multi-criteria analysis, AHP, DEM,
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Table of content

<table>
<thead>
<tr>
<th>Content</th>
<th>Page numbers</th>
</tr>
</thead>
<tbody>
<tr>
<td>Abstract</td>
<td>i</td>
</tr>
<tr>
<td>Acknowledgement</td>
<td>ii</td>
</tr>
<tr>
<td>Table of content</td>
<td>iii</td>
</tr>
<tr>
<td>List of abbreviations</td>
<td>v</td>
</tr>
<tr>
<td>1. Introduction</td>
<td>1</td>
</tr>
<tr>
<td>1.1 Aim of the study</td>
<td>1</td>
</tr>
<tr>
<td>1.2 About the study area</td>
<td>2</td>
</tr>
<tr>
<td>1.3 Literature review</td>
<td>2</td>
</tr>
<tr>
<td>2. An overview of GIS/MCA</td>
<td>6</td>
</tr>
<tr>
<td>2.1 Introduction to GIS</td>
<td>6</td>
</tr>
<tr>
<td>2.1.1 Data management, manipulation and analysis using GIS</td>
<td>6</td>
</tr>
<tr>
<td>2.1.2 Data input and output</td>
<td>7</td>
</tr>
<tr>
<td>2.1.3 Data storage</td>
<td>8</td>
</tr>
<tr>
<td>2.1.4 Visualization using GIS</td>
<td>8</td>
</tr>
<tr>
<td>2.2 Introduction to Multi-Criteria analysis</td>
<td>8</td>
</tr>
<tr>
<td>2.2.1 Key features of MCA</td>
<td>9</td>
</tr>
<tr>
<td>2.2.2 The performance matrix</td>
<td>9</td>
</tr>
<tr>
<td>2.2.3 Scoring and weighting</td>
<td>10</td>
</tr>
<tr>
<td>2.3 Different types of MCA</td>
<td>10</td>
</tr>
<tr>
<td>2.3.1 Basic AHP procedures</td>
<td>10</td>
</tr>
<tr>
<td>2.3.2 Outranking method</td>
<td>10</td>
</tr>
<tr>
<td>2.3.3 Linear additive method</td>
<td>11</td>
</tr>
<tr>
<td>2.3.4 MCA based on fuzzy set</td>
<td>11</td>
</tr>
<tr>
<td>2.4 Advantage of MCA over informal judgement</td>
<td>12</td>
</tr>
<tr>
<td>3. Materials and method</td>
<td>13</td>
</tr>
<tr>
<td>3.1 Satellite imagery</td>
<td>13</td>
</tr>
<tr>
<td>3.2 Digital elevation model (DEM)</td>
<td>14</td>
</tr>
<tr>
<td>3.3 Method</td>
<td>15</td>
</tr>
<tr>
<td>3.3.1 Image stacking</td>
<td>15</td>
</tr>
<tr>
<td>Abbreviation</td>
<td>Definition</td>
</tr>
<tr>
<td>--------------</td>
<td>------------</td>
</tr>
<tr>
<td>AHP</td>
<td>Analytical Hierarchy Process</td>
</tr>
<tr>
<td>CSI</td>
<td>Consortium of Spatial information</td>
</tr>
<tr>
<td>DEM</td>
<td>Digital elevation model</td>
</tr>
<tr>
<td>ESRI</td>
<td>Environmental Systems Research Institute</td>
</tr>
<tr>
<td>GI</td>
<td>Geographic information</td>
</tr>
<tr>
<td>GIS</td>
<td>Geographic information systems</td>
</tr>
<tr>
<td>GTC</td>
<td>Georgia transmission corporation</td>
</tr>
<tr>
<td>HRH</td>
<td>His Royal Highness</td>
</tr>
<tr>
<td>MCA</td>
<td>Multi-Criteria Analysis</td>
</tr>
<tr>
<td>STRM</td>
<td>Shuttle Radar Topography Mission</td>
</tr>
<tr>
<td>USGS</td>
<td>United States Geological Survey</td>
</tr>
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<td>UTM</td>
<td>Universal Transverse Mercator</td>
</tr>
<tr>
<td>WGS</td>
<td>World geodetic system</td>
</tr>
<tr>
<td>WRS II</td>
<td>Worldwide reference system-2</td>
</tr>
</tbody>
</table>
1. Introduction

Planning a road path to cater for the need of the people is complex and time consuming considering the time taken to define ground rules, define roles and responsibilities and as well put into consideration the different opinion of the stakeholders involved in the planning process, social and environmental needs as well as community and governmental interest. This complex process of planning in most cases might lead to the possibilities of not completing the plan and getting on with the implementation of the proposed project.

Effective road path is an essential interest of every developing country and it acts as a means of interconnectivity between different parts and regions within and outside the country. Miller and Shaw (2001) reported that the importance of transportation planning is that it acts as a guide towards development of land and transportation system in order to achieve beneficial economic, social and environmental outcomes.

Since 1980’s, GIS coupled with MCA has helped to enhance multi-criteria decision making associated with planning process (Roy, 1996). The use of GIS and MCA, which is a decision-aid and a mathematical tool allowing the comparison of different alternatives according to many criteria, has helped in the planning process and decision making in conflicting decisions. The use of MCA and GIS has helped as a guide for decision makers towards actualizing a desired choice and coupled with geographic information systems to enhance multi-criteria decision making (Chakhar & Martel, 2003).

In order to make road path planning and evaluation operational, they must be conveyed to decision makers in the most efficient and transparent way. The application of GIS and multi-criteria analysis as a decision making tool has helped in reducing the problems faced by decision makers. This means that the framework adopted during the evaluation must be made explicit so as to allow tracking of the influence of each factor on the evaluation results. This is optimally achieved with the use of GIS and MCA (Geneletti, 2004).

Planning a road path requires an extensive evaluation process in order to identify the best possible path the road can follow. This path must comply with the requirements of the government regulations and at the same time must minimize economic, environmental, health and social cost. The road path selection procedure using MCA and GIS make maximum use of the available information in trying to arrive at an outcome acceptable by most stakeholders and as such requires the processing of a variety of spatial data.

1.1 Aim of the study

The application of GIS and MCA as a decision making tool for complex planning in different sectors has taking over the traditional method of planning. This thesis is aimed at introducing the possibilities of using MCA and GIS as a tool for
complex planning in Nigeria with emphasis on the location of a road path between two points in the city of Lokoja, the capital of Kogi state.

In actualizing the aim of this thesis, satellite images over the area of study were obtained from the Landsat home page and analyzed. A digital elevation model (DEM) was obtained from Consortium of Spatial Information (CSI) and a slope model over the area was derived from the DEM. The expected final result to be obtained in this thesis is a map showing the possible road path between two points over the area of study.

1.2 About the study area

The study area for this thesis is the city of Lokoja, which is the capital of Kogi state in north-central part of Nigeria. Kogi state has a population of about 2.5 million inhabitants after the 1997 national census and richly blessed with mineral resources such as coal which is found in Okaba, Ogboyaga and Koton-Karte (E-Nigeria net, 2004). Kogi state is rated as the 24th most populated state out of the 36 states in Nigeria with agriculture as its mainstay of the economy.

Lokoja which is the main area of study for this thesis is the capital of Kogi state and forms a part of the Niger River. It is the centre of trade of agricultural region which sit at the confluence of the Niger Benue rivers (E-Nigeria net, 2004). Figure 1 below shows the map of Nigeria with the 36 states including Kogi.

![Figure 1, Map of Nigeria showing the 36 states. Source: E-Nigeria net, 2004](image)

1.3 Literature review

The application of MCA and GIS in planning purpose is not restricted only to road path planning, pipelines, power transmission line etc. MCA and GIS can be
used in different planning processes and the method and application is similar. The review of literature in this thesis helps to describe some of the published literature and journal in the application of Geographic information systems and multi-criteria analysis for planning purposes.

Sarkar, Sumathi, and Natesan (2007) carried out a research to determine the optimal site for a municipal waste landfill in the union territory of Pondicherry in India, which comprises of four interspersed geographical entities Pondicherry, Karaikal, Mahe and Yanam with an area of 492 km². Sarkar et al. (2007) used data from the topo-sheets of Pondicherry as the base map. The water bodies, road network and elevation maps were prepared based on the survey of Indian map by digitization. Other data like geology, soil, fault line, water supply source and ground water maps were obtained from other land department. The land use map over the area of study was obtained from the Indian remote sensing satellite.

Sarkar et al. (2007) used two approaches in determining the suitable site for a municipal solid waste landfill which include multi-level screening process to screen all environmental factors and secondly, using GIS constraint mapping to eliminate the environmentally unsuitable sites. The factors and constraints were weighted using the Analytical Hierarchy Process (AHP) to derive the relative important weight of each criterion and a pair-wise comparison was conducted among the criterion. In conclusion of their research, 17 potential sites were located that are suitable for setting a municipal solid waste landfill. Among the 17 potential sites, further screening was carried out and 3 most suitable sites were selected based on their area availability.

Yusof and Baban (2006) carried out a study to determine the least-cost reservoir pipeline path to the Langkawi Island, in Malaysia using geographic information system (GIS) and also to show how GIS can evaluate the suitable alternatives and visualize the results. The least-cost path was aimed at a major town Kuah and a new tourist area Temoyong. This was influenced by the land-use, terrain, and geological and environmental factors.

In actualizing the aim of the study, Yusof and Baban (2006) created a friction surface which helped to define the cost associated with moving through different land use/cover types around the area of study based on the analysis of the level of difficulty of the pipeline construction across physical features like land-use/cover, inland forest, rubber, mangrove, mixed horticulture, paddy and grass. The least-cost path was based on the selected reservoir and targeted areas from Ulu Melaka reservoir to Kuah town and from Limborg reservoir site to Temoyong on the potential forest resort areas.

The first step carried out was to select the start point, which was Ulu Melaka site and the destination, which was Kuah site. The cost distance analysis in the analysis need a friction surface that indicates relative cost of moving through each cells from the start to the destination point. In actualizing this, Yusof and Baban (2006) used the cost friction in IDRISI to create a friction surface. As a check on the influence of decision maker’s choice on MCA, Yusof and Baban (2006) changed the friction surface by changing the weights of paddy fields from 5 to 100 and that of rubber from 500 to 5. They used the cost and pathway function of IDRISI to calculate the least-cost path.
From there result, it was observed that when the friction surface of paddy is lower than rubber, the distance between Ulu Melaka and Kuah is 6.57km and from Limborg to Temyong 9.12 km. With a change in the friction surface making rubber lower than paddy, the result obtained changed with the distance from Ulu Melaka to Kuah now 6.3 km and Limborg to Temyong 9.33km. Yusof and Baban (2006) further concluded that decision makers preference in weighting criterion’s have an effect on the end results when determine least-cost path.

Berry (2000) carried out a study to describe the use of modified Delphi created by the Rand Corporation in the 1950’s, which is a technique designed to gather input from participants without them having facial contact and Analytical Hierarchy Process (AHP) for quantitatively establishing calibration ratings and data layer weights. The study further described a case of a new electric transmission line route determination using Delphi and AHP by the electric power research institute (EPRI) and Georgia transmission corporation (GTC) in determine an optimal path for an electric transmission line in Georgia.

In their study, Berry (2000) described the use of traditional method of electric transmission line determination which includes huddling around paper maps, sketching hundreds of possible path and assessing the feasibility to visualizing the best route as time wasting and in most cases does not yield the best required result. Berry (2000) said the use of least-cost path, which is based on user-defined criteria for sitting linear features and corridors helps to develop discrete cost surface that indicates the relative preferences, generate an accumulated cost surface characterizing the optimal connectivity from start to end and identifying the path of least resistance from desired end location.

In the sitting of an electric transmission line, Berry (2000) identified four factors of interest that constitutes the criterions to be considered before making a decision. These factors include high housing density, distance from road, near or within sensitive areas and high visual exposure to houses. The discrete maps collected from the field were translated into decision criteria calibrations were 1 is preferred and 9 is least preferred. The final derived map is then calculated using a computer.

In conclusion of Berry (2000) research, he used the evidence of the research of EPRI and GTC transmission line sitting in central Georgia to certify his research and the use of Delphi process as a decision making tool. In the research carried out by EPRI and GTC, Delphi process and AHP were used to calibrate weights with 20 criteria. With the use of the Delphi process and AHP, the different stakeholders were able to come to a conclusion on the best suitable route for the sitting of an electric transmission line in central Georgia without facially seeing each others.

A study on a selected area in Trabzon situated at the black sea region of Turkey was carried out by Yildirim, Nisanci and Reis (2006) in order to determine the least-cost path for a pipeline between Macka County and Bulak village. The least-cost path analysis was carried out in order to determine the difference in the present distance between the two points and the result obtained using least-cost path analysis.
Yildirim et al. (2006) used topo-maps, geological and road maps to get the route, and used other maps, fieldwork, and remote sensing techniques. The data layers used in the analysis include slope, geology, land-use, landslide, soil, stream, road, administrative boundaries and tourism. Yildirim et al. (2006) used ArcGIS 9.0 spatial analysis module to create source, generate a thematic cost map, perform cost weighted distance, create direction dataset and perform shortest path with distance and direction datasets.

Yildirim et al. (2006) used the weighting rate scheme to add weights to landslides, land-use, elevations and geology in order of importance with landslide been the first. In conclusion of their study, it was realized that new pipeline route path determined using the least-cost method was 36 km as against the original pipeline length which was 38 km. Yildirim et al. (2006) further concluded that the choice of preferences by the decision makers might have a significant effect on the result but the result obtained using the least-cost method to determine the best pipeline route is more accurate and less time consuming unlike the traditional method.
2. An overview of GIS/MCA

This chapter only gives a general overview on the application of geographic information systems and multi-criteria decision analysis. This is aimed at describing to first time users the basic principles and concept associated with MCA and GIS. Considering the fact that this thesis is an introduction to the application of GIS and MCA in road path planning in Nigeria, it is necessary to have an overview about GIS and MCA.

2.1 Introduction to GIS

Longley, Goodchild, Maguire, and Rhind (2002) described geographic information system (GIS) as a computer based information system used to digitally convert analog to digital application and keep track not only of events, things or activities but also the point where these activities occur. It helps to represent and analyze the geographic features present on the earth surface and the events including non-spatial attributes linked to the geography under study that are taking place on it (Longley, Goodchild, Maguire & Rhind, 2002).

Bernharden (2002) mentioned that since the mid 1970’s, specialized computer systems have been developed to process geographical information in many different ways. The GIS includes not only hardware’s and software’s but it also include special devices used to input maps and to create map product together with communication systems needed to link various elements. A GIS makes it possible to link or integrate information that is difficult to associate through any other means and can use combinations of mapped variables to build and analyze new variables (Bernharden, 2002).

Geographic information systems have a wild range of applications which include researchers incorporation of mapmaking process of traditional cartographers into GIS technology for the automated production of maps, resource management, scientific investigations, asset management, environmental impact assessment, urban planning, sales, marketing and logistic, etc (Aronoff, 1993).

2.1.1 Data management, manipulation and analysis using GIS

Data management component comprises of functions needed to store and retrieve data from the database. The methods used to implement these functions affect how efficiently the systems perform all operations with the data (Aronoff, 1993).

Data manipulation and analysis using GIS helps to determine the information that can be generated by the geographic information system (Aronoff, 1993). Every geographic information system has a distinguishing features and their ability to manipulate and integrate spatial and attribute data (Aronoff, 1993).

In the management of data and analysis using geographic information systems, the components of the geographic information (GI) include all available functions of the GIS that are needed to store and retrieve data from the data base. The
Manipulation and analysis of data in a geographic information system is not automatically achieved. The users are required to be involved in the specification of the necessary functions and performance levels of the systems (Aronoff, 1993).

Different GIS(s) have their ability and functions to manipulate and analyze data depending on the functions available in the geographic information systems. Some of the possible functions of a GIS include measurement functions, which enable the calculation of associated points, lines, areas and volume classification and rectification which helps to transform the attribute data associated with a single map layer and involves the grouping of objects into classes according the new values entered by the user in specification of the different classes needed. Other function of the GIS for manipulating and analyzing data include scalar operation, overlay operations, connectivity operations, visualization of data, etc (Malczewski, 1999).

2.1.2 Data input and output

Data input and output can not be automatically carried out by the Geographic information systems on its own without the user specification. The function of the input component of the GIS is to convert the inputted data from their existing form to another form that can be used by the geographic information systems. The data used as input and output could be printed (hardcopy) or digital. The printed media could be of paper maps; tables of attribute, photos, etc, while the digital data could be of electronic files of maps and associate attribute data, air photos, and even satellite imagery (Aronoff, 1993).

The data input procedures could be an easy and straight forward process or a complex one. Aronoff (1993) mentioned that the process of data input could be a daunting task if the existing form of data differs greatly from the one used in a GIS or the data amount is huge and sometimes the conversion process itself is daunting. Data input can influence the result that is expected at the output of the geographic information systems as such the data input should be taken into deep account as possible errors in the data input could cost organization more and more money to fix and suit it with the need of the organization. The various method of data entry should be evaluate in terms of the processing to be done, the accuracy standards to be met and the form of output to be produced (Aronoff, 1993).

The data output in geographic information systems is a result in charts, maps, table of value or text in hard copy or soft copy. Maps that have been derived from the inputted data and the information produced are then to be printed or displayed as output of GIS. The output or reporting functions of geographic information systems vary more in quality, accuracy and ease of use than in the capabilities available (Aronoff, 1993). There are a variety of output devices, which includes display monitors, pen plotters, electronic plotters, laser printers, etc. The output functions are determined by the users need in two formats, which is the display and transfer formats. The display output format presents the information to be the GIS user in some form while the transfer formats transfer the information into another computer based system for further processing and analysis (Malczewski, 1999).
2.1.3 Data storage

When working with GIS data, it is necessary to understand how various forms of GIS data are stored in their native format. This understanding is critical in order to be successful in moving GIS datasets around. For example, an ESRI shape file is just one file but a grouping of multiple files that work together to create a more efficient method of storing spatial and tabular data, yet keeping the association.

The manner in which a digital map is stored in a record is determined by a format, a set of instructions specifying how the data are arranged in fields. Different software’s often organize data to ensure effective use. Most GIS data are arranged in layers much like convectional map-making and the individual data layers are stored in individual data files. GIS data can be stored in vector data format, raster data, attribute data, etc (Bernharden, 2002).

The storage components of a GIS include those functions that are needed in the GIS to store and retrieve data from its database. The efficiency of the data performance with the system is determined by the way and method used for the data performance, and the way and methods for the data storage (Malczewski, 1999). Malczewski (1999) suggested that it is advisable that there is an understanding of the elements of computer storage which will enable a GIS user to design optimum storage for different types of data.

2.1.4 Visualization using GIS

Maps have traditionally been used to explore the earth. GIS technology has enhanced the efficiency and analytical power of traditional cartography. Through visualization, a GIS can be used to produce images not just map, but drawings, animations and other cartographic product. These images allow researchers to view their subjects in ways that they never could before. The images often are helpful in conveying the technical concept of a GIS to non-scientist (Bernhardsen, 2002).

2.2 Introduction to Multi-Criteria analysis

MCA is designed to be an interactive and flexible management tool for geographic analysis and it is well suited for modeling complex sustainability issues. In the context of conflict resolution and policy implementation, MCA decision models are one of the oldest forms of geographical analysis. Their structures consist of an explicit set of objectives decided upon by a decision maker or an expert group for the purpose of determining an optimal solution (Malczewski, 1999). The optimal solutions are recommended through the set of alternatives that satisfy the largest extent of the expert group objectives. MCA is well suited for conflict resolution as many problems incorporate a wide range of highly complex information that otherwise would be overwhelming for manual aggregation or subjective to high levels of human error (Malczewski, 1999).
The main role of the MCA technique is to deal with difficulties that human decision makers have shown to have in handling large amount of complex information in a consistent way (Malczewski, 1999). MCA can be used to identify a single most preferred option, to rank option, to short-list a limited number of options for subsequent detailed appraisal or simply to distinguish acceptable from un-acceptable possibilities. There are many different types of decision, which fit the broad circumstances of MCA, these are influenced by the time taken to undertake the analysis which may vary, the analytical skills of those supporting the decision, etc (Malczewski, 1999).

Malczewski (1999) reported that Multi-criteria analysis is well suited to managing and evaluating structural programs in partnership since the opinions of national and supranational members may be expressed jointly without losing any of their specificity or having to make too many concessions regarding their value scales and the analysis is similar to the techniques adopted in the field of organizational development or information systems management.

2.2.1 Key features of MCA

MCA establish preferences between options by reference to an explicit set of objective that is the decision making body as identified and for which it has established measurable criteria to assess the extent to which the objectives may alone provide enough information for decision-makers (Aronoff, 1993). MCA uses models that help to predict how certain aspects of the real world will behave and it helps to describe the relationship among data elements in order to predict how events in the real world will occur. In MCA, quality or result that is obtained is determined by the data and criterion selection by the MCA user (Aronoff, 1993).

A key feature of MCA is its emphasis on the judgment of the decision making team in establishing objective and criteria, establishing relative importance weights and to some extent in judging the contribution of each option performance criterion. An MCA foundation in principle is the decision maker’s own choice of objective, criteria, weights and assessments of achieving the objectives (Malczewski, 1999).

2.2.2 The performance matrix

Performance matrix is one of the features of MCA and it usually applies two types of techniques, which includes scoring and weighting. It is a form of a consequence table in which each row describes an option and each column describes the performance of the options against each criterion. In a basic MCA, the performance matrix can act as a final result analysis where the objectives are met based on the entries in the matrix. This may not be the same for the case of a more sophisticated analytical MCA. In this case, the information is basically converted into consistent numerical values (Malczewski, 1999).
2.2.3 Scoring and weighting

A performance matrix in MCA usually applies two types of techniques for its numerical analysis, which is scoring and weighting. Scoring and weighting in MCA uses mathematical routines which may be written in computer programs and helps in both scoring and weighting to give an overall assessment of each option been assessed for its quality (Malczewski, 1999). The use of scoring and weighting in MCA is dependent on the individuals that will be providing the inputs that are required to produce the detailed information that is consistent with the preferences that have been identified by the individual input (Malczewski, 1999).

In the scoring techniques, the expected consequence of each option are assigned a numerical score on the strength of preference scale for each criterion with more preferred option having higher scores and lower option having lower scores (Malczewski, 1999). In the weighting option, numerical weights are assigned to define for each criterion and the relative valuation of a shift between the top and bottom of the chosen scale. Different methods can be used in the application of weights, which include ranking, rating, pair-wise comparison and trade-off analysis (Malczewski, 1999).

2.3 Different types of MCA

There are many different types of MCA. This thesis have looked and given a brief description of some MCA techniques.

2.3.1 Basic AHP procedures

The Analytic Hierarchy Process allows users to assess the relative weight of multiple criteria (or multiple alternatives against a given criterion) in an intuitive manner. Its major innovation was the introduction of Pair-wise comparisons which is a method that has been shown by researchers that when quantitative ratings are unavailable, human are still adept at recognizing whether one criterion is more important than another (Malczewski, 1999). Saaty (1980) is the inventor of the AHP methodology and he established a consistent way of converting such pair-wise comparisons into a set of numbers representing the relative priority of each of the criteria (Malczewski, 1999).

Malczewski (1999) reported that a potential drawback with the AHP method is the rank reversal. Because judgment in AHP is relative by nature, changing the set of alternatives may change the decision scores of all the alternatives. Even when a new very poor alternative is added to a completed model, the alternatives with top scores sometimes reverse their relative ranking (Malczewski, 1999).

2.3.2 Outranking method

The outranking method starts by making comparison of alternatives for each single criterion in order to denote partial binary resolution (Roy & Vanderpooten,
Outranking is used where the criteria are not all considered commensurable, and therefore no global score can be produced. The analysis is based on multiple comparisons of the type for example, does Measure A outrank Measure B from the point of view of the environment criterion and does Measure A outrank Measure B from the point of view of the employability criterion etc (Roy & Vanderpooten, 1996). Roy and Vanderpooten (1996) suggest that these questions can be answered yes or no or be qualified, in which case the notions of a weak preference and a threshold criterion are introduced and the analysis makes all possible comparisons and presents a synthesis of the type.

Outranking methods constitute a class of ordinal ranking algorithms for multi-criteria decision-making. The outranking method of MCA was developed in France and has achieved a fair degree of application in some continental European countries and it is based on the concept of outranking. Weighting in outranking are measured by the degree to which each criterion influences a final statement of whether or not alternative A is equal or preferred to B. The key feature about outranking is that they allow for two or more alternatives to remain incomparable if there is insufficient argument to support that one alternative outranks the other. The main concern about outranking is that it is dependent on some rather personal decision of what precisely constitutes outranking and how the threshold parameters are set and manipulated by the decision maker (Roy & Vanderpooten, 1996).

2.3.3 Linear additive method

The linear additive method of MCA shows how option value on the many criteria can be combined into one overall value by multiplying the value core of each criterion by the weights of that criterion and then adding all those weights scores together. The linear additive methods can be operationalised using any GIS system having overlay properties (Malczewski, 1999).

The use of linear additive method can be applied to both raster and vector GIS environment and there are two strong assumption in the additive method of MCA which is linear and additive of attributes. In the linearity assumptions, the desirability of an additional unit of an attribute is constant for any level of that attribute while in the additivity of attributes; there is no interaction effect between the attributes (Malczewski, 1999).

2.3.4 MCA based on fuzzy set

The MCA method of fuzzy set shows the many ways with which fuzziness can be introduced into an existing model of decision-making. There are different types of fuzzy set method among which include the fuzzy additive weighting method which is similar to the linear additive method. Both methods apply the weighted average as the aggregation operator and the difference between this two methods is that the fuzzy additive weighting method operates on the fuzzy data were the entries of the decision matrix and weights are specified in terms of fuzzy numbers (Malczewski, 1999).
Fuzzy sets attempt to capture the idea that our natural language in discussing issues is not precise as options are fairly attractive from a particular point of view or rather expensive. The fuzzy arithmetic then tries to capture these qualified assessments using the idea of a membership function through which an option would belong to the set of options with a given degree of membership lying between 1 and 0 (Malczewski, 1999). Different types of models have applied the principles of fuzzy set among which include the Bellman-Zadeh model. This model of Bellman-Zadeh serves as a point of departure for most subsequent work on decision in fuzzy environment (Malczewski, 1999).

2.4 Advantage of MCA over informal judgement

The features and application of MCA have helped me distinguish it from the informal method of planning. The informal method of planning employs the use of crude instruments, takes time and resources etc. I present some possible advantages of MCA over informal method of planning.

- MCA is open and explicit. That is MCA is done or shown in an open or direct way so that there is no doubt about what is happening
- The use of MCA saves time and resources
- There is a chance of an audit trial because of the use of scores and weight
- MCA provides a better communication among the decision makers and the entire community
- Choice and criteria are open to analysis by different stakeholders involved in the planning process and possible changes can be made if found not suitable
- With the availability of data, MCA can be carried out without direct visitation to the area of study
- With the use of MCA, planners do not go through the rigorous task of continual site visitation and working under bad weathers. The analysis and planning process is carried out using different software and a computer and as such can be done indoors.
3. Materials and method

This chapter describes the materials and method that has been used in this thesis. The input for the analysis is restricted to a slope map derived from an elevation model and a land use map derived from a satellite image over the area of study.

3.1 Satellite imagery

The satellite imagery for this thesis is a Landsat TM (Thematic Mapper), which was obtained from the Landsat home page http://www.landsat.org/ortho/index.htm. The satellite image over the area is shown in Figure 2 below.

![Figure 2, Satellite image.](image)

The original satellite image over the area of study was obtained from WRS II path/row 189054, and the image was produced on the 27th of March 2002 by 17:18 pm. The satellite image consists of different bands and each band is registered with different wavelengths that have different purposes and characteristics. The original satellite image was reduced to 54 km by 69 km to cover the required area of study. The basic characteristics of the different bands of the satellite image used for the thesis are shown in table 1 below.
Table 1. Different bands and characteristics of a satellite image

<table>
<thead>
<tr>
<th>Band</th>
<th>Wavelengths</th>
<th>Colour</th>
<th>Main Purpose</th>
<th>Resolution</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0.45-0.52 μm</td>
<td>Blue</td>
<td>Maximum penetration of water which is useful for bathymetric mapping in shallow water, Useful for distinguishing soil vegetation and deciduous from coniferous plants</td>
<td>30m</td>
</tr>
<tr>
<td>2</td>
<td>0.53-0.61 μm</td>
<td>Green</td>
<td>Matches green reflectance peak of vegetation which is useful for Assessing Plant vigor</td>
<td>30m</td>
</tr>
<tr>
<td>3</td>
<td>0.63-0.69 μm</td>
<td>Red</td>
<td>Matches a chlorophyll absorption band that is important for discriminating vegetation types</td>
<td>30m</td>
</tr>
<tr>
<td>4</td>
<td>0.78-0.90 μm</td>
<td>Near infrared</td>
<td>Useful for determining biomass content and for mapping shorelines</td>
<td>30m</td>
</tr>
<tr>
<td>5</td>
<td>1.55-1.75 μm</td>
<td>Mid infrared</td>
<td>Indicates moisture content of soil and vegetation penetrates thin clouds and provides good contract between vegetation types</td>
<td>30m</td>
</tr>
<tr>
<td>6</td>
<td>10.40-12.50 μm</td>
<td>Thermal infrared</td>
<td>Nighttimes images are useful for thermal mapping and for estimating soil moisture</td>
<td>120m</td>
</tr>
<tr>
<td>7</td>
<td>2.09-2.35 μm</td>
<td>Mid infrared</td>
<td>For mapping hydro-thermally altered rocks associated with mineral deposits</td>
<td>30m</td>
</tr>
</tbody>
</table>

Source: Sabins F. F (1996 p 74)

3.2 Digital elevation model (DEM)

A digital elevation model (DEM) is used to represent a ground surface or a terrain and in some cases can be referred to as a digital terrain model (DTM). The DEM can be in form of a raster or a triangular irregular network (Gallant & Hutchinson, 2006). Digital elevation models (DEMs) are commonly built using remote sensing techniques like in the case of the Shuttle radar topographic mission (SRTM) digital elevation data and they can also be built from land surveying (Gallant & Hutchinson, 2006). DEM is required in a variety of applications which include flood or drainage modeling, land-use studies, geological applications, etc and in most cases are common basis for digitally-produced relief maps that are used in geographic information systems (Gallant & Hutchinson, 2006).

The digital elevation model used for the analysis was obtained from the website of the Consortium of Spatial Information (CSI). The DEM is an SRTM 90 m DEM and has a resolution of 90m at the equator, and was provided in mosaiced 5 deg x 5 deg tiles for easy download and use (Jarvis, Reuter, Nelson & Guevara, 2008).
The DEM data is distributed free of charge by USGS and is available for download from the National Map Seamless Data Distribution System, or the USGS ftp site for easy download and mosaicing from the website http://srtm.csi.cgiar.org/ The DEM obtained from the CSI are available in ArcInfo, ASCII and GeoTiff format to facilitate their ease of use in a variety of image processing and GIS applications (Jarvis et al. 2008). Figure 3 shows the DEM over the area of study.

![Figure 3, DEM. Source: Jarvis et. al. 2008](image)

3.3 Method

3.3.1 Image stacking

The original DEM and satellite image used for this thesis are in .tiff file format. This file is readable by Erdas but because of the different layers that make up images, there was a need to stack them together in order to obtain a single satellite image. In stacking the satellite image, a model maker in Erdas software was used. In the model maker as shown in figure 11 on the appendix, three icons were created which include input icon, function icon and output icon.

There are seven input icons and each icon represent the individual band in the satellite image. The function icon is used for stacking all the .tiff files together while the output icon contains the final image file after stacking. The DEM has a single layer and as such was converted to an image file. The DEM was originally projected in latitude and longitude Clarke 1886 while the satellite image has a projection of universal transverse Mercator (UTM) in a world geodetic system (WGS). For the images to be in the same projection, the reproject image under data preparation in Erdas was used to reproject the DEM to UTM/WGS 84.
3.3.2 Subsetting images

The original satellite image and the DEM over the area of study for this thesis as cover areas that are outside the intended area of study. In obtaining a reduced image that covers specifically the area of study, subset under data preparation in Erdas software was used to reduce both images. On the subset window, the image to be reduced is imputed and the user specifies the coordinates of the area with which is needed and the software computes and reduces the image to the specified coordinates.

3.3.3 Slope map from DEM

The slopes help to identify the maximum rate of change in surface value over a specific distance and they are expressed in degrees or percentage. In actualizing the slope map from the DEM required for the final thesis analysis, the spatial analyst tool in ArcMap 9.2 was used in the slope map calculation. Calculate slope is one function of many in spatial analyst tool and this function was used to derive the slope map from DEM.

3.3.4 Deriving land-use map from Satellite image

The land-use map used for the thesis was derived from the satellite image. The land-use map is used to differentiate between the different terrains over the area of study and the classification of an image involves sorting of the image pixels into a specified number of classes or categories based on the intensity values of the data file (Lillesland & Kiefer 1999). In actualizing the different land-use types, unsupervised classification was carried out on the satellite image.

The unsupervised method of land-use classification involves the use of algorithms which examines the unknown pixels in an image and the pixels are then aggregated together into a number of classes based on natural grouping of clusters present in the image spectra class (Lillesland & Kiefer 1999). Figure 4 shows the raster attribute table that was used in controlling the classification. In the attribute table, 60 classes were created. This was to have a better representation of the different land-use classes over the area of study. The different classes were recoded using recode under interpreter/GIS analysis in Erdas software. The five different classes used for the analysis include water, open area, agriculture, forest and farm settlement. The overall classification accuracy is 88.94%. The accuracy assessment table for the classification is shown in figure 13 on the appendix.
3.4 Model creation

After the data preparation, the next step is the creation of the model. The creation of the model requires a spatial analysis toolbox in ArcGIS. The spatial analysis in ArcGIS is a comprehensive tool for GIS analysis. The created model helps to derive information from the available data used in identifying spatial relationship, finding suitable locations and the calculation of the accumulated cost of traveling from one point to another.

In creating the model, a new toolbox was created below the toolboxes and from the toolbox, a new model was created. The properties needed were entered in the model properties and this helps to describe what the model is to be used for. In the case of this thesis, the model is to be used to find the best route for a new road between two points in Lokoja, Nigeria based on a slope map and a land use map. Figure 14 on the appendix shows the created model. The blue boxes in the model are used to represent maps that must exist before the analysis while the yellow and green boxes are the functions and intermediate maps and end results.

3.4.1 Reclass slope map

The slope map was reclassified into a relative friction cost of 10 classes in order to have a common value. The slope map classification was achieved using symbology under the diagram properties in the model. In the classified slope map, 1 was used to represent good areas with low cost value to build a road while 10 represent bad, which is a high cost to build a road. The reclassification of the slope map will help in differentiating the different slopes between the different slope classes during criteria evaluation and as such provides a proximity surface on the best area to construct the road path.
3.4.2 Land-use weighting/classification

With the reclassified slope map, it is necessary to reclassify the land use map. The reclassed land-use map helps to differentiate a bad from good areas to build a road path. In actualizing the land-use reclassification, the first thing is to weight the different land-use type against each other. The land-use weighting was carried out using the Analytical Hierarchy Process (AHP), which involves pair-wise comparisons to create a ratio matrix. The AHP used in the weighting of the land use criteria in this thesis was obtained from the website [http://www.hig.se/~sab/software/software.html](http://www.hig.se/~sab/software/software.html) and shown in figure 10 on the appendix.

Weights of the parameters were calculated and prioritized in this order: Water, forest, agriculture, farm settlement and open area as shown in the AHP in the appendix. In the weighting, agriculture has twice the cost of open areas, and agriculture is half the weights of forest, while forest has four times the weight of open areas, etc. Water has the highest weight of 10 showing that it has the highest friction and as such is very expensive to build a road across water. After determination of the comparative weight of parameters, the derived weights were manually inserted in the land-use map. These weights are used in weight averaging the map layer to identify an overall suitability map.

To ensure that both the land-use map and the slope map are of the same classes, the land-use map containing the relative weights was reclassified into 10 classes. In actualizing this, symbology under the diagram properties in the model was used setting the method to equal interval.

Two maps have been produced in the model namely reclass slope and reclass land-use. The two maps were combined into one total cost map using AHP. In this case the land-use factor is considered to be twice as important as the slope factor. The map layers are multiplied by the relative weights and the product summed using the map algebra in the spatial analysis toolbox. Subtracting the suitability maps based on the AHP derived weights helps to identify area of agreement that is appropriate for routing a road path at each map location.

3.4.3 Creating road path start and destination point

To compute a distance over a rough or friction surface, there is a need to specify the start and destination points with which the part is to follow. The source feature is the image that indicates the cells from which cost should be determined, which is an integer with cells indicated by a zero value. The start and destination points for the road path was created using ArcCatalog 9.2. Two new shape files start point and destination points were created and the cost path in the distance menu in the cost dialogue box was use in the calculation. This start and destination points were not created as stand-alone points. This was to ensure that the route points created was within the coordinates of the area under study.
The start point is on an approximate coordinate of 219002, 958986 meters and the destination point on an approximate coordinate 320322, 878101 meters. The green and red spots in figure 5 show the start point and destination points of the road path on the satellite image. The two points where randomly selected.

![Figure 5, Map showing start and end points for the road path](image-url)
4. Intermediate Result

This chapter of the thesis describes some of the intermediate results that were obtained during the analysis of the data. These intermediate results obtained were analyzed to actualize the final result that was needed in the thesis.

4.1 Land use classification

The different land-use classes were used to differentiate the different terrains over the area of study and these was used in the final judgment on the best alternative to determine the best route path. The usefulness of this result is that the land-use map helps to understand what the different available land-use over the area of study is being used for as well as the available features that are present in the area.

The result obtained from the land use classification is a land-use map over the area of study. This land-use map was classified into five classes which include open area, farm settlement, agriculture, forest and water. Figure 6 is the land-use map over the area.

![Figure 6, Land-use map over the study area](image)

4.2 Reclassed slope map

The result of the reclassed slope map over the area of study is a map that helps to differentiate the slope classes hence creating an opportunity in choosing the best area to construct the road path. The derived slope map over the area of study is shown in figure 7. In this map, low slopes are in the dark areas of the map and this represents low cost to build a road and has the value 1 while high slopes which signifies high cost to build a road are in light areas and has a value 10.
4.3 Reclassed land use

The result of the reclassed land-use is a land-use map with different classes representing different friction surface suitable for the road path. With the reclassification, land-use with high friction surface and high cost to build a road like water have the value 10 and represented with blue on the map while low cost surface like open area have the value 1 and land-use color black. Figure 8 shows the reclassed land-use.
5. Final result

The final result obtained in this thesis is a map over the area of study showing the possible route path for a road obtained using GIS and MCA. Figure 9 shows the result obtained after the final analysis of the different data.

Figure 9, Final map showing possible road route path
6. Discussion

The purpose of this thesis was to introduce the usability of GIS and Multi-criteria analysis into the Nigeria planning system with emphasis on the planning of a route path between two points using Lokoja the capital of Kogi state as a case study. The use of GIS approach in this thesis has helped in incorporating digital layers of various different scales. In order to minimize environmental impacts and to achieve sustainable development in route path determination, it is essential to determine the relative importance of the considered parameters. There are so many different methods for the determination of parameters and the selection of a method depends on the trade-offs between ease of use, accuracy, the degree of understanding on the part the decision maker, and the theoretical foundation underlying a given method, the availability of computer software, and the way the method can be incorporated into GIS-based multi-criteria decision analysis.

In this thesis the Analytical Hierarchy Process which uses a pair-wise comparison matrix was used to determine the relative importance of the parameters. Empirical applications suggest that the pair-wise comparison method is one of the most effective techniques for spatial decision-making including GIS-based approaches (Malczewski, 2006). It is recommended to consider environmental and civil expert’s views regarding to relative priority of the parameters. Other methods like outranking method etc were not tested in this thesis. This is because of my understanding and handling of the AHP.

In this thesis, the weighting of the criterion was based on personal understanding of the area used for the thesis. The consideration of the views of other experts might have a significant effect on the final result. This conforms to the conclusion of Yusof and Baban (2006) in their analysis on a least cost pipeline path to the Langkawi Island in Malaysia were they concluded that the decision makers preference in weighting criterion’s have an effect on the end results when determine least-cost path. These also conforms to the report by Yildirim, et al. (2006) were they further concluded that the choice of preferences by the decision makers might have a significant effect on the result but the result obtained using the least-cost method to determine the best pipeline route is more accurate and less time consuming compared to the traditional method.

Erdas software was used in the mapping of the land-use. The usability of other software's for land-use mapping was not tested in this thesis and as such their usability could not be ascertained. In Nigeria, Erdas software is available software and as such will be available for use in areas of land-use mapping. Considering the period of the year (27th of March) the satellite image was produced, this is a period in Nigeria when the rain density is still very low and the water bodies are low. This may have a significant effect on the result compared to satellite images produced in July when there is high rain density and increased water body.

The use of ArcGIS desktop which includes ArcMap, ArcCatalog and Arc tool box has proven reliable in managing, integrating, performing advanced analysis, model and automated operational processing of data as well as displaying final results. The ArcGIS desktop tools are available in Nigeria and as such it is possible to perform the operations in this thesis in Nigeria which are related to the
application of ArcGIS desktop. One limitation observed during my visit to Nigeria during this thesis is the instability of energy and non efficient internet connections as this hindered the effective analysis of the data. Most part of Nigeria don’t have Land-use/land cover maps and as such any person carrying out land-use classifications or mapping have to depend on his or her own personal knowledge and understanding of the area been mapped. Another alternative is to visit the area been mapped as it was in the case of this thesis.

Considering the result obtained in this thesis, it is possible to determine a route path between two points over an area without having a direct contact with the area. The application of MCA and GIS in planning process has proven to be less time consuming and as well reduce cost associated with traditional method of planning. One major problem about the use of MCA and GIS in planning process is that it has to be conducted by an expert who has the knowledge in the use and applications of GIS and MCA. As a result of this, the application of GIS and MCA is not a general and easy application as one need to have expertise knowledge.

The MCA and GIS result in route planning in Nigeria presented in this focused mainly on the application of MCA and GIS and the possibilities of carrying out planning processed using these tools. The criterions selected for the analysis were based on individual understanding and as such different stakeholder’s opinion were not consulted.

In a situation where there are more stakeholders involved in the planning process, the actual decision making will be more complex than what is presented here because other concerns and opinions will be at stake and the choice of criterion selection will defer when other stakeholders are involved in the planning process. It is advisable that site visitation is carried out physically to ascertain the result obtained in the analysis using GIS and MCA. This is because there might be some monumental structures and other landmarks that were not accounted for during the weighting of criterions for the best route path.
7. Conclusion and recommendations

Planning a route path is complex and brings a lot of challenges to route planners. The course of the complexity in the planning process comes from the consideration of different factors which must be considered in the analysis. In conclusion, the final result obtained in this thesis supports other researches in the application of GIS and MCA in complex planning. The result has demonstrated the possibilities of applying GIS and MCA principles and techniques in actualizing a route path avoiding the rigorous method of route planning using the traditional method.

The possibility of using GIS and Multi-criteria analysis in complex planning process in Nigeria has been successfully shown in this thesis. GIS and MCA can be used not only in route planning but other planning process like the research of Sarkar, et al. (2007) where GIS and MCA was used in the setting of a municipal solid waste landfill in the union territory of Pondicherry. The application of GIS and Multi-criteria analysis is a complex study that needs in-depth knowledge and understanding.

Based on the experience gained during this thesis, the following recommendations were made:

- The Nigerian government should ensure that land-use map over the different regions of Nigeria be mapped out. This can be achieved using GIS experts in collaboration with the other agencies in Nigeria to actualize the mapping out of the land-use/land cover types.
- The use and application of GIS and Multi-criteria analysis in planning should be introduced to Nigeria universities as this will help eliminate the crude method of planning processes.
- In the planning process in Nigeria, different stakeholders view should always be considered in order to have a collective solution that could help minimize cost and save time.
- The Energy as well as internet systems in Nigeria should be improved in order to create room for easy analysis and interpretation of data using GIS.
- The application of MCA and GIS in other planning processes should be carried in order to determine the usability in Nigeria.
- The effect of different DEM resolution on the final result of a GIS and multi-criteria analysis should be carried out to determine the effect of resolution of the final results of GIS and MCA analysis.
- The effect of different environmental expert’s views on the final result of a GIS and MCA analysis.
9. References


Appendix

Figure 10, AHP pair-wise comparison matrix

Figure 11, Model maker
Maps that must exist before analysis: Intermediates

Functions:

Intermediate maps and end result:

Figure 12, Created Model

Figure 13, Accuracy assessment table