Application of GIS as Support Tool for Pavement Maintenance Strategy Selection

Adeleke O. O.[1*], Kolo S. S.[2], Odumosu J. O.[3], Abdulrahman H. S.[2] and Atilola B. Y[1]
[1]Dept. of Civil Eng., Univ. of Ilorin, Ilorin, Nigeria
[2]Dept. of Civil Eng., Federal Univ. of Tech., Minna, Nigeria
[3]Dept. of Surveying and Geomatics, Federal Univ. of Tech., Minna, Nigeria

*Corresponding author: Tel. +234 8060812278 email: adeleke.oo@unilorin.edu.ng

ABSTRACT

Pavement Management System (PMS) is set of tools or methods that can assist decision makers in finding cost effective strategies for providing, evaluating, and maintaining pavement in a serviceable condition. The paper reports how ArcGIS software is used as a decision support tool for the maintenance of road networks; the University of Ilorin paved road network is taken as a case study. Pavement Surface Evaluation and Rating was performed on each road in the network using pavement condition rating form and scale. Spatial and as patial information of the road network which include the digital map of the road network, the coordinates of defect's location, defect type and size etc. were used to develop a relational database. The database developed in EXCEL software was imported into ArcGIS software to allow for ease of analysis and query of the database and ease of visual and graphical displays of results. The developed package which can easily be updated lends itself to simple and multiple queries of the database such as 'what is where and where is what'. Results of queries on the pavement condition rating, the needed maintenance budget for the roads and statistical analyses are given in the paper. It is recommended that relevant agencies in the field of road maintenance should explore the use of GIS for the maintenance of pavements and other roadway assets to enhance decision making process.

Keywords: Pavement condition, Pavement maintenance, GIS, Decision making

1. Introduction

Roads are the major channel of transportation for carrying goods, passengers and services. The deterioration of these roads will fast affect the transportation system with consequent adverse effects on the socio-economic activities of a nation; thus the responsibility for proper maintenance and management of the road system by the supervising agencies. The major goal of a highway agency is to use public funds to provide a comfortable, safe and economical road surface. This requires balancing priorities and making difficult decisions in order to manage the pavements effectively. Managing local roads involve three useful steps (i) inventory of all roads and streets (ii) periodic evaluation of the condition of all pavements and (iii) usage of the condition evaluations to set priorities for projects (Wisconsin Transportation Information Centre, 2002). This demand on highway agencies has led to the development of various Pavement Management Systems (PMS). A PMS is defined as a set of tools or methods that can assist decision makers in finding cost effective strategies for providing, evaluating, and maintaining pavement networks in a serviceable condition (WNCHRP, 2004).

The conventional methods of locational referencing and Road Pavement management were not suitable for comprehensive computerization of highway information (Lagunzad and McPherson, 2003). Road information is geospatial and has recently being managed in Geographic Information System (GIS) environment (Robert, 2011). GIS integrates hardware to facilitate the management, analysis and graphical representation of all forms of geospatially referenced data. It allows the user to interpret, question, track and visualize data in ways that will establish trends, patterns and relationships, in the form of maps, reports and charts. GIS helps answer questions and solve problems by looking at data in a way that is quickly understood and easily shared to allow for better decision making. The infusion of GIS has benefited the PMS development and implementation effort in these regards (Smadi, 2004). GIS for example, has been used in pavement management in roadway condition assessment, maintenance strategies and improvement recommendations, prioritization of roadway improvements, and development of preliminary cost estimate (Robert, 2011). This realisation coupled with the need to enhance and improve on Pavement Management (PM) in the study area informed the decision for the study which can serve as prototype for other PM agencies.

2. Aim and objectives

The aim of the study is to develop a GIS-based PMS package which will provide a systematic process for collecting, analyzing and summarizing pavement condition information to support the selection and implementation of cost effective pavement maintenance programs. The paved road network of the main campus of the University of Ilorin, Ilorin, Nigeria is used as a case study. The objectives are as follows:

i. map out the road network of the Unilorin main campus
ii. evaluate the condition of the road pavement
iii. identify the appropriate maintenance and rehabilitation project needs on the road
iv. develop a GIS database of the spatial and attribute data of the road network and
v. Prioritize the allocation of financial resources based on outcomes of GIS analyses.

3. Literature review

3.1 Defects in flexible pavements

Defects in flexible pavements are indicative of road distress and impaired efficiency. They may be due to poor performance of constituent materials, errors in design or construction, environmental and climate factors as well as to particularly heavy traffic. Two types of defects may be distinguished: functional and structural. Functional defects express shallow degradation of the wearing course of pavements; this degradation reduces both vehicle grip to the road and evenness of the road surface and thus jeopardizing traffic safety. Factors responsible for this type of degradation and giving rise to skid resistance problems include leveling (or polishing) of aggregates; surface exposure of bitumen (known as bitumen blooming) and detachment of aggregates. Smoothness problems comprise longitudinal undulations, transverse undulations (more commonly called ruts), hollows or bulges, dips on extensive surfaces and edge cracking. Conversely, structural defects arise in the supporting courses of the superstructure. They are due to deterioration of its load-bearing capacity and have major repercussions on pavement durability. Defects of this type encompass surface cracks and breaks and more recurrently, longitudinal, and transverse cracks, longitudinal cracks only, transverse cracks only, ramified cracks (spider or alligator cracks) and failures (Colograndе et. al., 2011; Wisconsin Transportation Information Centre, 2002).

3.2 GIS Applications

The use of Geographic Information System (GIS) in pavement management is utilized at different levels and covers the different steps from developing to implementing a pavement management system. GIS is used in the design of the PMS database, in the data integration process (inventory, history, condition, etc) and finally in communicating the results of the PMS (Smadi, 2004). Because the data used in the decision-making process in PMS have spatial components, the use of spatial technologies such as GIS and GPS have been very appealing. Georgia Department of Transportation (GDOT) for example has adopted and been actively using GIS technology to improve its 28,962-km system's highway pavement management since 2000 (Robert, 2011). The GDOT scheme includes an Oracle client/server and a GIS-based pavement management module. Shanghai airport pavement system (SHAPMS) has also been developed and updated for the Hongqiao and Pudong international airports that also utilize the power of GIS for data collection, data storage, geospatial analysis of pavement evaluation and optimization of maintenance planning (Meng, et al, 2012).

3.3 Global Positioning System

The use of Global Positioning System (GPS) in the data collection process (inventory of condition) is a very useful tool in the pavement management development process and implementation. Referencing all collected information geographically by capturing their coordinates makes the data integration and representation as efficient as possible. (Smadi, 2004).

3.4 Pavement Condition Rating

Pavement surface defects can be distinguished and quantified visually by human or automated techniques (Wisconsin Transportation Information Centre, 2002). Generally rating procedures involve observing and recording the presence of specific defect type followed by a description of its severity and then the quantification of its extent to which the road surface is affected by the defect. Pavement Condition Rating (PCR) is a value from 0 to 100 computed for each road segment or project, where 100 indicates no defects. Where there are defects the PCR is obtained by subtracting a 'Deduct' value from 100. 'Deduct' is a number from 0 to 100 that is assigned to a combination of defects observed in a pavement segment. It is obtained by assigning deduct value to each distress type and its levels of severity and extent. The deduct values in a given segment or road are summed together and subtracted from 100 to compute the final PCR for the segment or road.

4. Materials and methods

i. Road network

The study area and major adjoining features were mapped using Garmin GPS reciever, this provided the base map.

ii. Pavement Evaluation and Rating

Pavement Surface Evaluation and Rating was performed on each of the roads using pavement condition rating form and pavement condition rating scale. A visual conditional survey was conducted by walking through the road lengths. Data collected during the exercise include:

- defect type
- geographic location of each defect (X,Y,Z coordinates) was captured with GPS
- the severity of defect,
- the extent to which the road surface is affected by the defect i.e measure of the area, length or count associated with the defect

iii. Maintenance cost determination

This is the preparation of the financial implication of the failed sections of the roads. In order to have an accurate maintenance cost analysis a well prepared proposal format on road maintenance was used for the costing.

iv. Data processing and analyses

The collected data which includes the defect type, defect location, extent etc were input into EXCEL, processed as appropriate and imported into ArcGIS Software (9.3 Version) for further analyses and presentation of results.

5. Results and Discussion

5.1 Results

5.1.1 Road inventory

The roads in the network include: Senior quarters road, Unilorin stadium bypass, Unilorin main road, Olu Daramola road, Afolabi Toye road and Abdullahi Mohammed road which have a total length of 15.5 km. The lengths of the roads are shown in Table 1 while Fig. 1 is the road network showing some adjacent structures.

Table 1: Road Length

Section	Road name	Road distance (km)
A	Senior quarter`s road	3.553
B	Unilorin stadium bypass	0.699
C	Unilorin main road	5.191
D	Olu Daramola road	1.486
E	Afolabi Toye road	2.640
F	Abdullahi Mohammed road	1.937

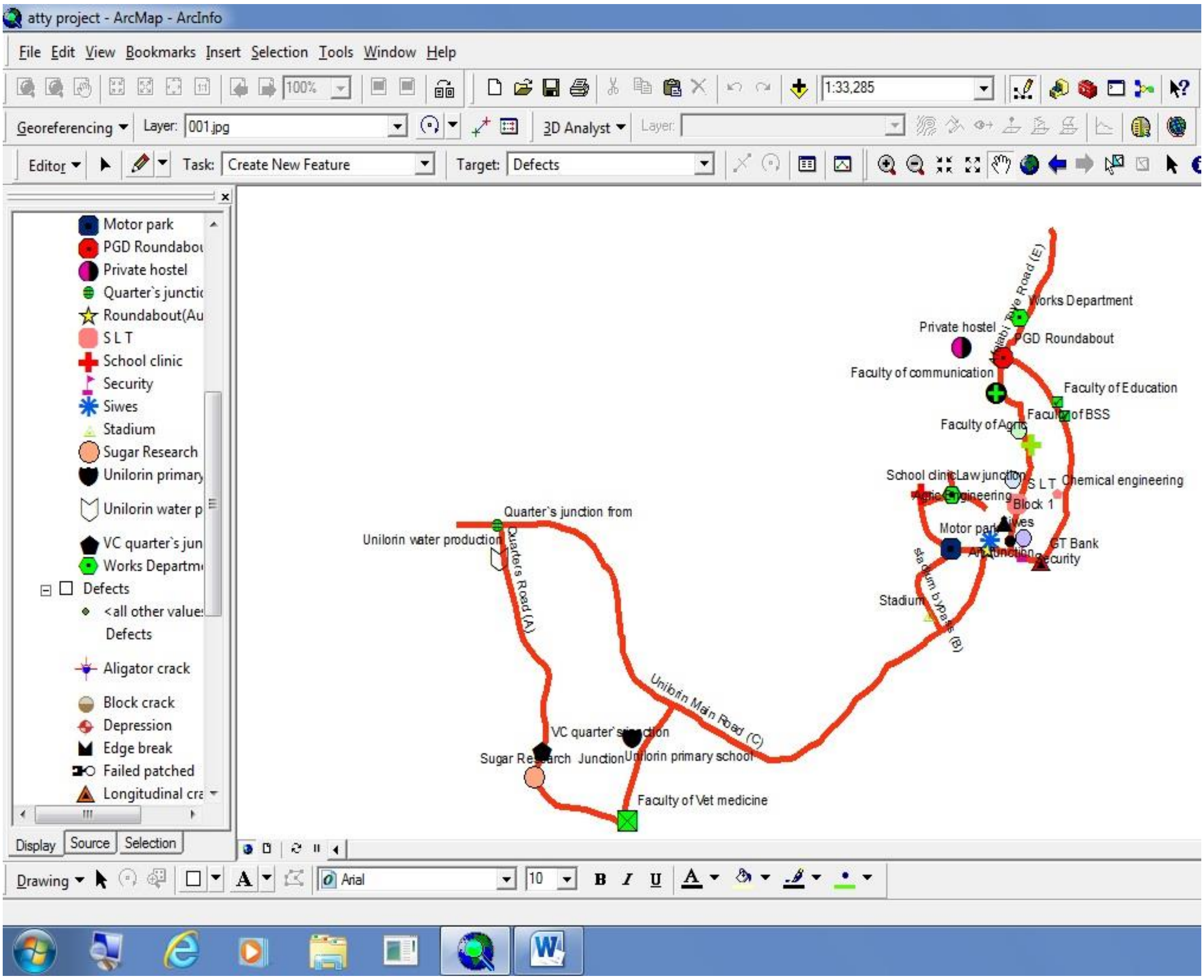


Fig. 1: The Road Network of Unilorin (Paved Section)

5.1.2 Identified defects

The defects identified on the roads include: Longitudinal crack, Transverse crack, Potholes, Failed patches, Ravelling, Bleeding, Rutting, Depression, Edge break. Fig. 2 and Fig. 3 show the positions of the defect types for road sections A, B and C and road sections D, E and F respectively.

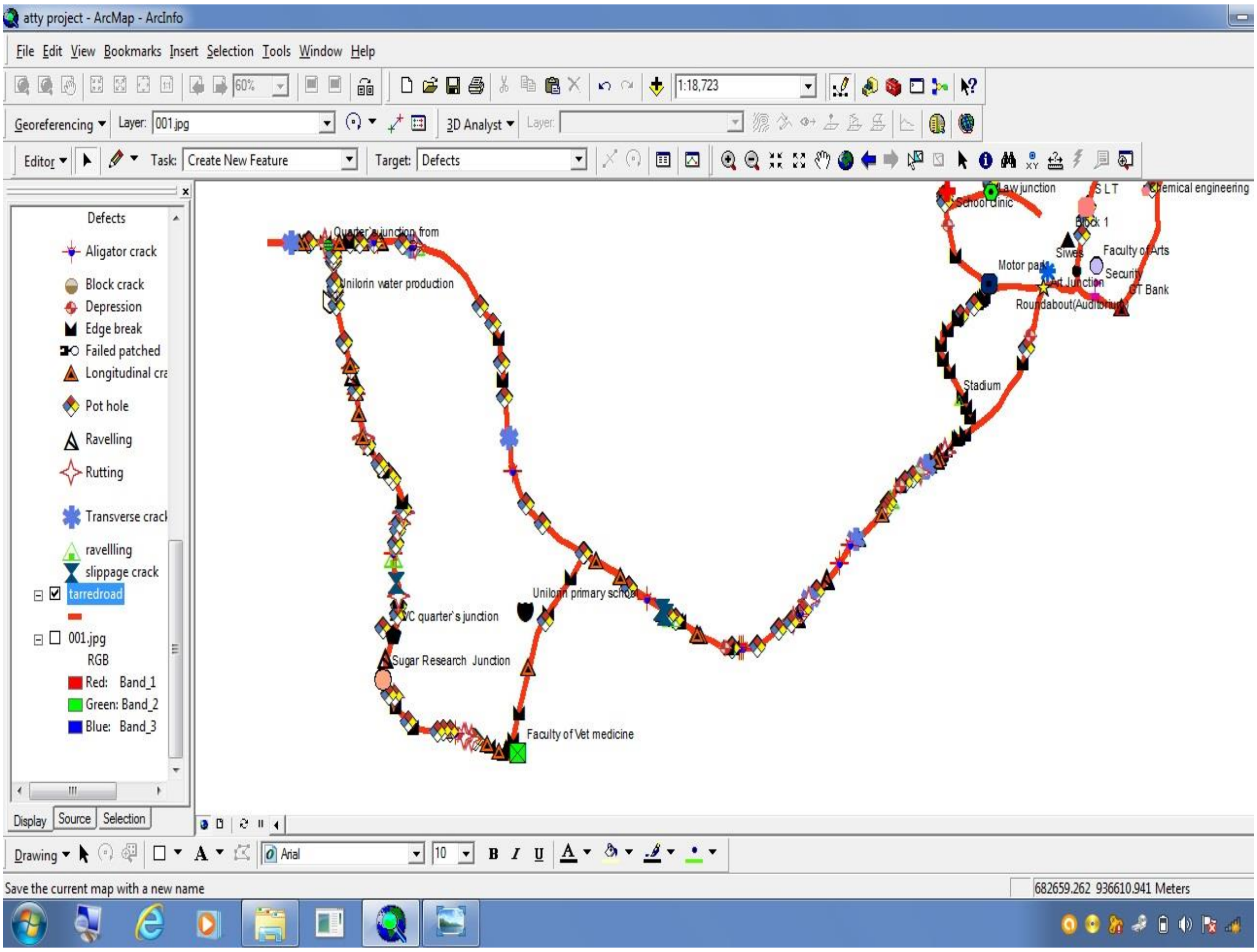


Fig. 2: The Database of Sections A, B and C

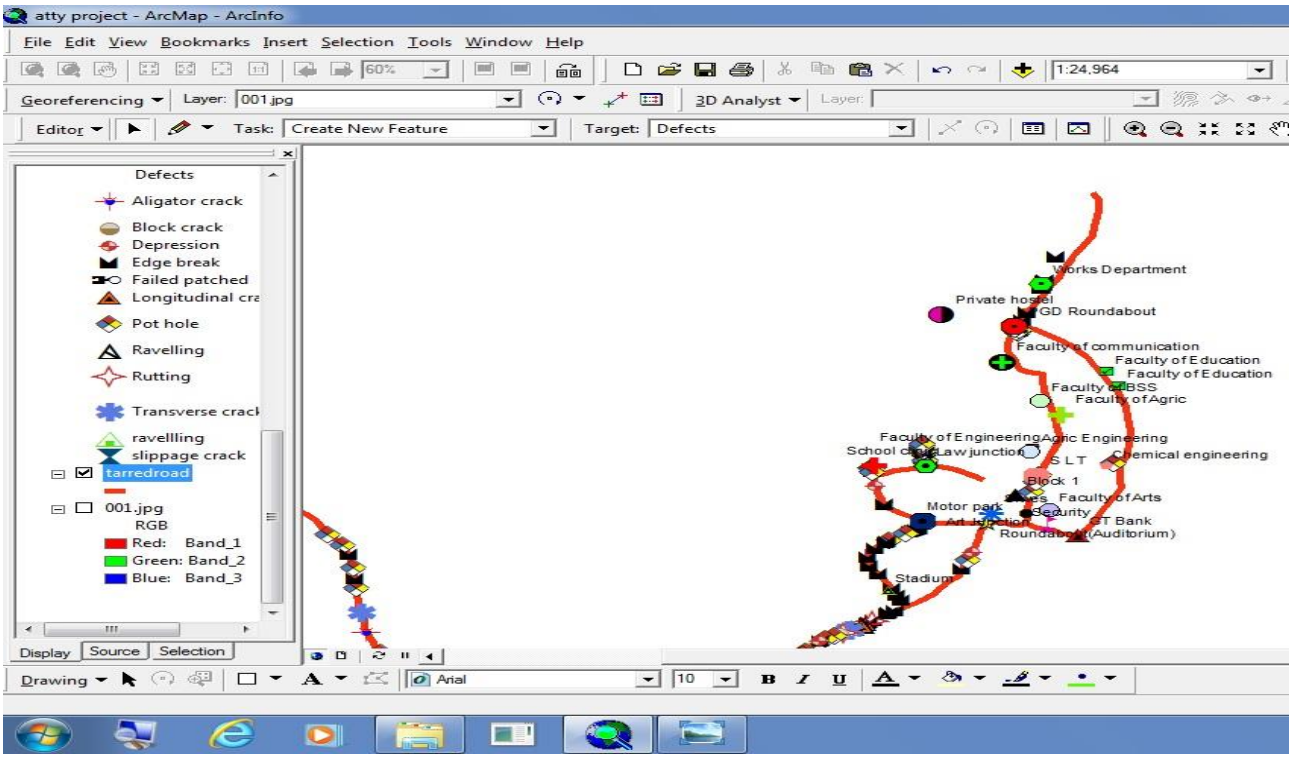


Fig. 3: The Database of Sections D, E and F

5.1.3 Pavement Condition Rating (PCR)

Pavement condition rating form and rating scale were used as guide in the study.

The PCR is obtained as

100 – TOTAL DEDUCT = PCR (pavement condition rating)

while

DISTRESS WEIGHT x SEVERITY WT x EXTENT WT = DEDUCT POINT

The pavement condition rating form for Section C is shown in Table 2 as an example: the percentage of ravelling on the road which is below 20% gave 0.5 (EXTENT) from the PCR form which is used to multiply standard 0.3 (L SEVERITY WT) and 10 (DISTRESS WT) to obtain 1.5 (DEDUCT POINT). The obtained deduct point of each defect added together gave the TOTAL DEDUCT which is subtracted from 100 to give the percentage condition of the road.

The results of the pavement condition rating of Section A to Section F are shown in Table 3.

5.1.4 Database Development

An EXCEL file containing the defects coordinates, defect extent, cost etc was imported into the ArcGIS using the “Add XY Data” tool. The data which was thus converted into shapefile is shown as attributes in Fig. 4 and Fig. 5.

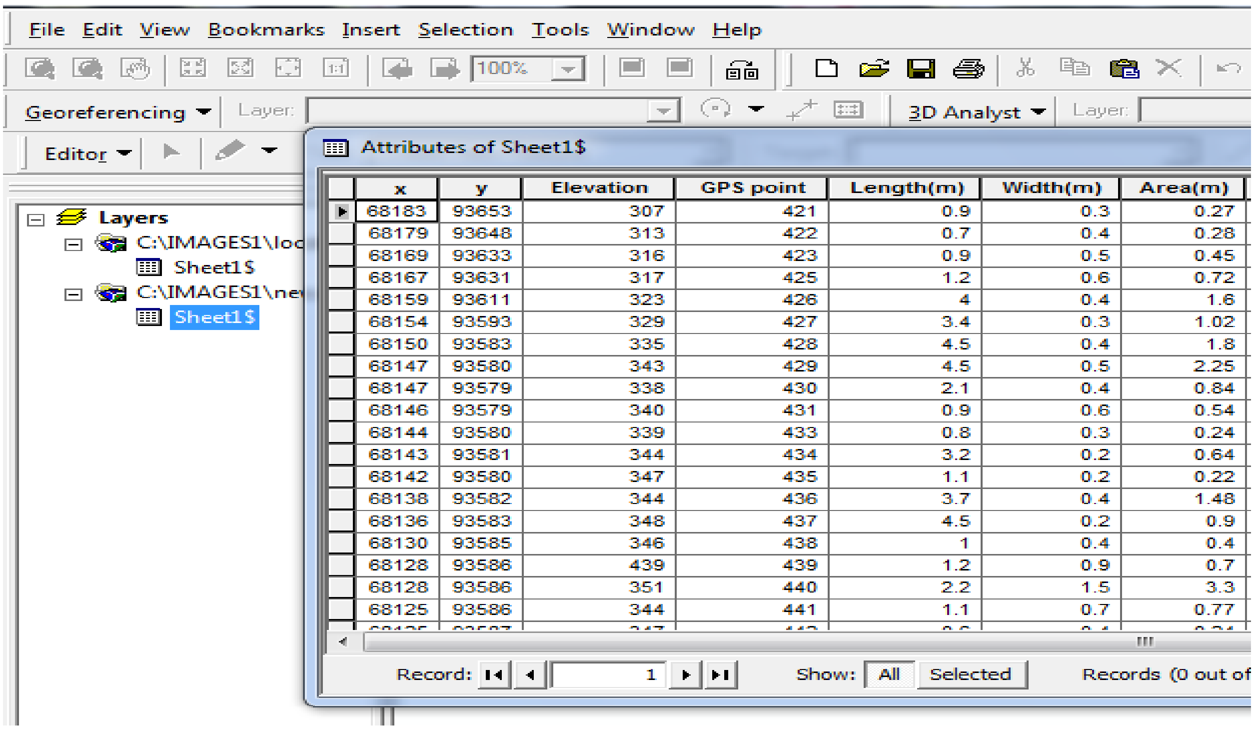
Table 2: Pavement Condition Rating of Unilorin main road (Section C)

DISTRESS	DISTRESS WEIGHT	SEVERITY WT.*			EXTENT WT.**			DEDUCT POINT***
		L	M	H	O	F	E	
RAVELING	10	0.3	0.6	1	0.5	0.8	1	10 X 0.3 X 0.5 = 1.5
BLEEDING	5	0.8	0.8	1	0.6	0.9	1	0
PATCHING	5	0.3	0.6	1	0.6	0.8	1	5 X 0.3 X 0.6 = 0.9
POTHOLES/ DEBOUNDING	10	0.4	0.7	1	0.5	0.8	1	10 X 0.7 X 0.8 = 5.6
CRACK SEALING DEFICIENCY	5	1	1	1	0.5	0.8	1	0
RUTTING	10	0.3	0.7	1	0.6	0.8	1	10 X 0.7 X 0.8 = 5.6
SETTLEMENT	10	0.5	0.7	1	0.5	0.8	1	0
CORRUGATION	5	0.4	0.8	1	0.5	0.8	1	0
WHEEL TRACK CRACKING	15	0.4	0.7	1	0.5	0.7	1	15 X 0.4 X 0.5 = 3
BLOCK AND TRANSVERSE CRACKING	10	0.4	0.7	1	0.5	0.7	1	10 X 0.4 X 0.5 = 2

LONGITUDINAL JOINT CRACKING	5	0.4	0.7	1	0.5	0.7	1	5 X 0.7 X 0.7 = 2.45
EDGE CRACKING	5	0.4	0.7	1	0.5	0.7	1	5 X 0.7 X 0.7 = 2.45
RANDOM CRACKING	5	0.4	0.7	1	0.5	0.7¤	1	0
*L= LOW **O= OCCASIONAL						TOTAL DEDUCT =		23.5
M= MEDIUM F= FREQUENT								
H= HIGH E= EXTENSIVE						100 – TOTAL DEDUCT = PCR =		76.5
***DISTRESS WT x (SEVERITY WT) x (EXTENT WT) = DEDUCT POINT								

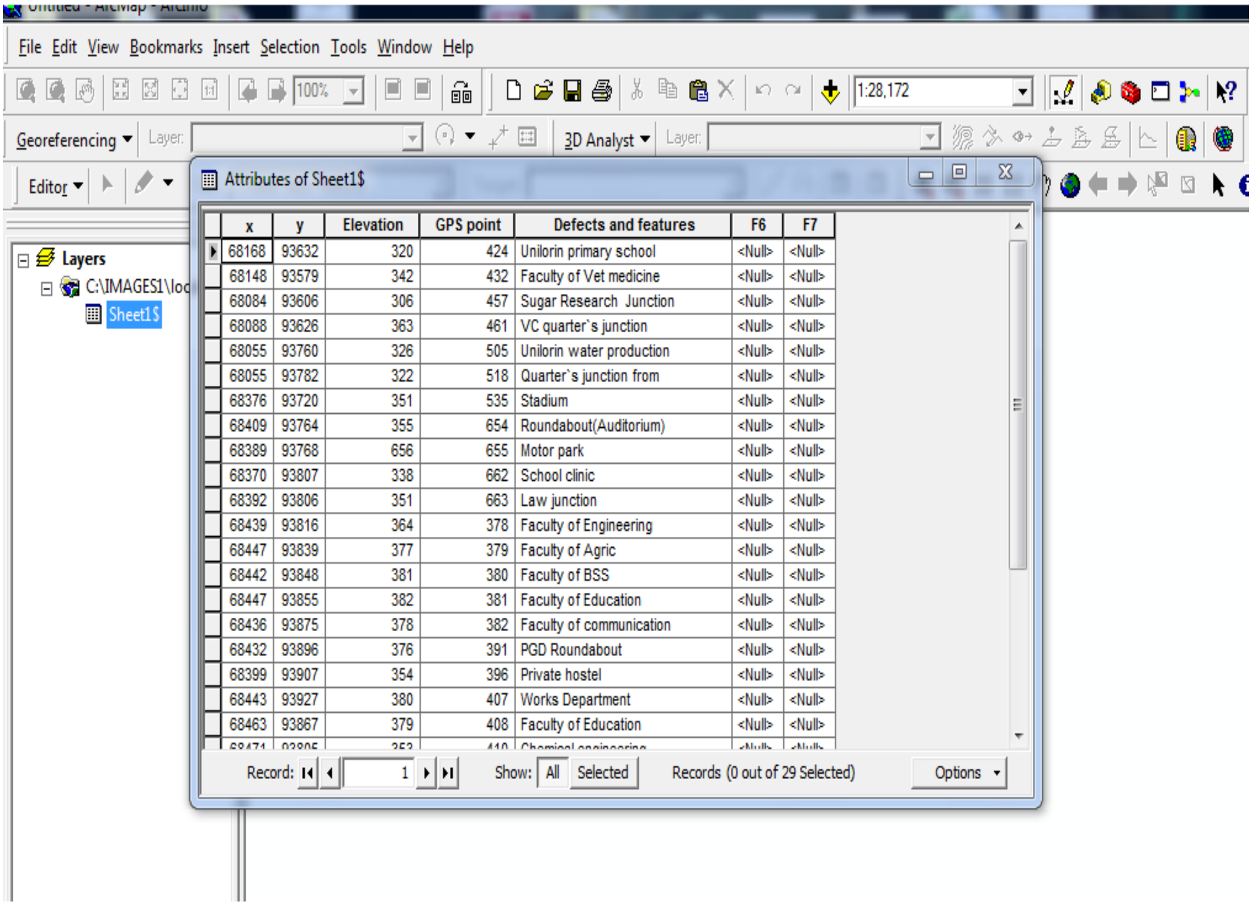
Table 3: PCR Results

Section A	Section B	Section C	Section D	Section E	Section F
68.4 Fair	82.5 Good	76.5 Fair	86.5 Good	93.0 V Good	98.0 V Good



x	y	Elevation	GPS point	Length(m)	Width(m)	Area(m)
68183	93653	307	421	0.9	0.3	0.27
68179	93648	313	422	0.7	0.4	0.28
68169	93633	316	423	0.9	0.5	0.45
68167	93631	317	425	1.2	0.6	0.72
68159	93611	323	426	4	0.4	1.6
68154	93593	329	427	3.4	0.3	1.02
68150	93583	335	428	4.5	0.4	1.8
68147	93580	343	429	4.5	0.5	2.25
68147	93579	338	430	2.1	0.4	0.84
68146	93579	340	431	0.9	0.6	0.54
68144	93580	339	433	0.8	0.3	0.24
68143	93581	344	434	3.2	0.2	0.64
68142	93580	347	435	1.1	0.2	0.22
68138	93582	344	436	3.7	0.4	1.48
68136	93583	348	437	4.5	0.2	0.9
68130	93585	346	438	1	0.4	0.4
68128	93586	439	439	1.2	0.9	0.7
68128	93586	351	440	2.2	1.5	3.3
68125	93586	344	441	1.1	0.7	0.77

Fig. 4: Defects data



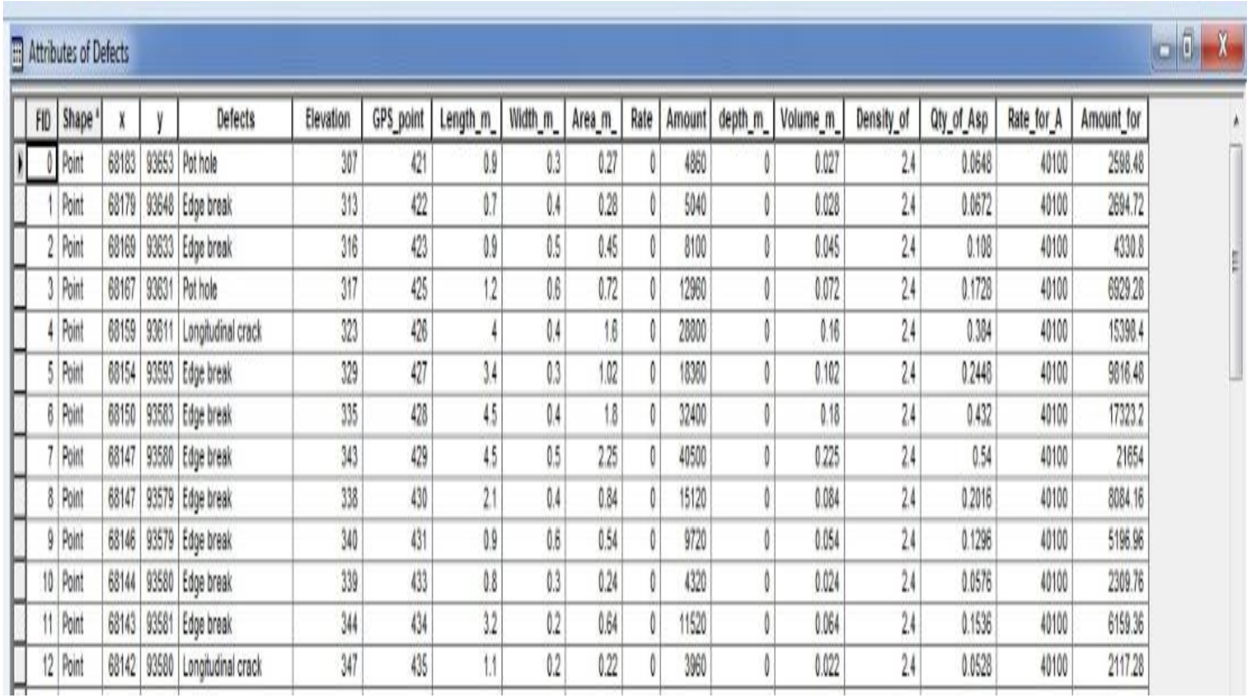
x	y	Elevation	GPS point	Defects and features	F6	F7
68168	93632	320	424	Unilorin primary school	<Null>	<Null>
68148	93579	342	432	Faculty of Vet medicine	<Null>	<Null>
68084	93606	306	457	Sugar Research Junction	<Null>	<Null>
68088	93626	363	461	VC quarter`s junction	<Null>	<Null>
68055	93760	326	505	Unilorin water production	<Null>	<Null>
68055	93782	322	518	Quarter`s junction from	<Null>	<Null>
68376	93720	351	535	Stadium	<Null>	<Null>
68409	93764	355	654	Roundabout(Auditorium)	<Null>	<Null>
68389	93768	656	655	Motor park	<Null>	<Null>
68370	93807	338	662	School clinic	<Null>	<Null>
68392	93806	351	663	Law junction	<Null>	<Null>
68439	93816	364	378	Faculty of Engineering	<Null>	<Null>
68447	93839	377	379	Faculty of Agric	<Null>	<Null>
68442	93848	381	380	Faculty of BSS	<Null>	<Null>
68447	93855	382	381	Faculty of Education	<Null>	<Null>
68436	93875	378	382	Faculty of communication	<Null>	<Null>
68432	93896	376	391	PGD Roundabout	<Null>	<Null>
68399	93907	354	396	Private hostel	<Null>	<Null>
68443	93927	380	407	Works Department	<Null>	<Null>
68463	93867	379	408	Faculty of Education	<Null>	<Null>

Fig. 5: Data on features along the roads

5.1.5 Cost Analysis

This involves the importation of the cost data into the GIS software to prepare the budget for each section of the road network as shown in Fig. 6. The costing was obtained as follows:

i. Compute the defect volume by: Defect area x Average depth
ii. Compute tonnage of asphalt required by: Volume of defect x 2.4
iii. Compute total cost of asphalt by: Asphalt tonnage x rate per ton
iv. Compute cost of workmanship by: Defect area x Maintenance rate per m^2
v. Compute total cost of maintenance: Total cost of material + Total cost of workmanship



Attributes of Defects

FID	Shape *	x	y	Defects	Elevation	GPS_point	Length_m_	Width_m_	Area_m_	Rate	Amount	depth_m_	Volume_m_	Density_of	Qty_of_Asp	Rate_for_A	Amount_for
0	Point	68183	93653	Pot hole	307	421	0.9	0.3	0.27	0	4860	0	0.027	2.4	0.0648	40100	2598.48
1	Point	68179	93648	Edge break	313	422	0.7	0.4	0.28	0	5040	0	0.028	2.4	0.0672	40100	2694.72
2	Point	68169	93633	Edge break	316	423	0.9	0.5	0.45	0	8100	0	0.045	2.4	0.108	40100	4330.8
3	Point	68167	93631	Pot hole	317	425	1.2	0.6	0.72	0	12960	0	0.072	2.4	0.1728	40100	6929.28
4	Point	68159	93611	Longitudinal crack	323	426	4	0.4	1.6	0	28800	0	0.16	2.4	0.384	40100	15398.4
5	Point	68154	93593	Edge break	329	427	3.4	0.3	1.02	0	18360	0	0.102	2.4	0.2448	40100	9816.48
6	Point	68150	93583	Edge break	335	428	4.5	0.4	1.8	0	32400	0	0.18	2.4	0.432	40100	17323.2
7	Point	68147	93580	Edge break	343	429	4.5	0.5	2.25	0	40500	0	0.225	2.4	0.54	40100	21654
8	Point	68147	93579	Edge break	338	430	2.1	0.4	0.84	0	15120	0	0.084	2.4	0.2016	40100	8084.16
9	Point	68146	93579	Edge break	340	431	0.9	0.6	0.54	0	9720	0	0.054	2.4	0.1296	40100	5196.96
10	Point	68144	93580	Edge break	339	433	0.8	0.3	0.24	0	4320	0	0.024	2.4	0.0576	40100	2309.76
11	Point	68143	93581	Edge break	344	434	3.2	0.2	0.64	0	11520	0	0.064	2.4	0.1536	40100	6159.36
12	Point	68142	93580	Longitudinal crack	347	435	1.1	0.2	0.22	0	3960	0	0.022	2.4	0.0528	40100	2117.28

Fig. 6: Cost analysis for the road network

5.1.6 Database Query

The main objective of pavement condition rating is to serve as a support tool in planning budgets and priorities. The database was queried to attain this purpose. The queries include both simple and multiple queries.

5.1.6.1 Query on the pavement condition rating

The pavement condition of each section of the road network was queried by the GIS and the result is shown in Fig. 7.

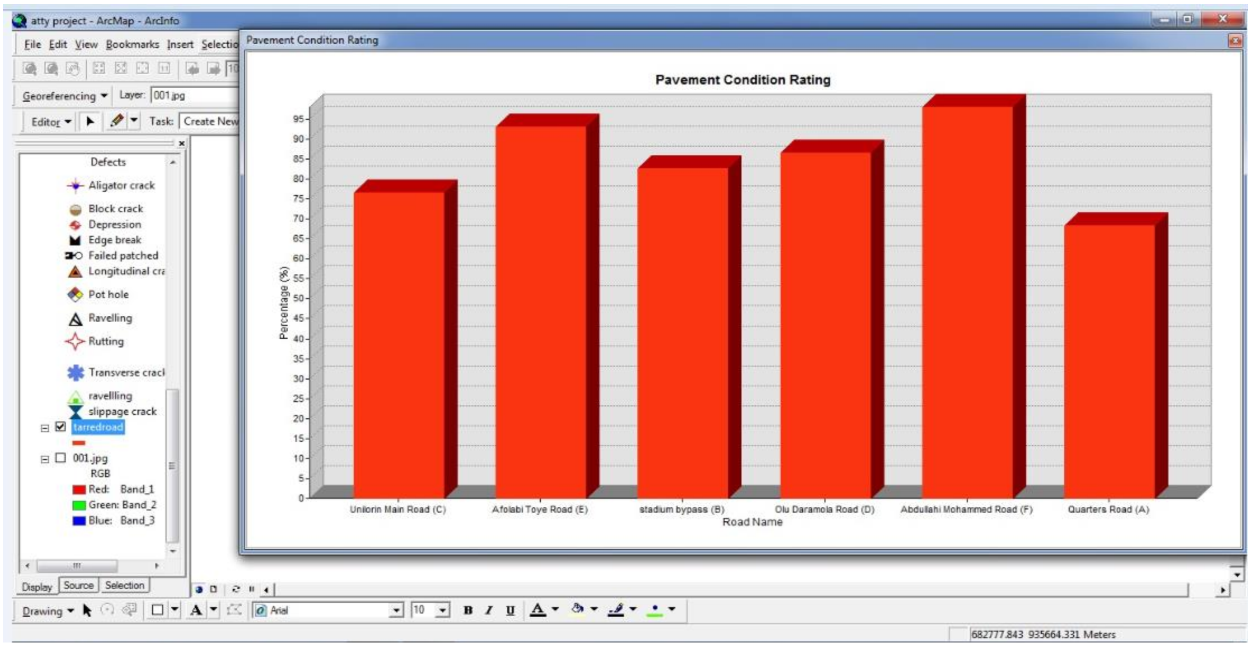
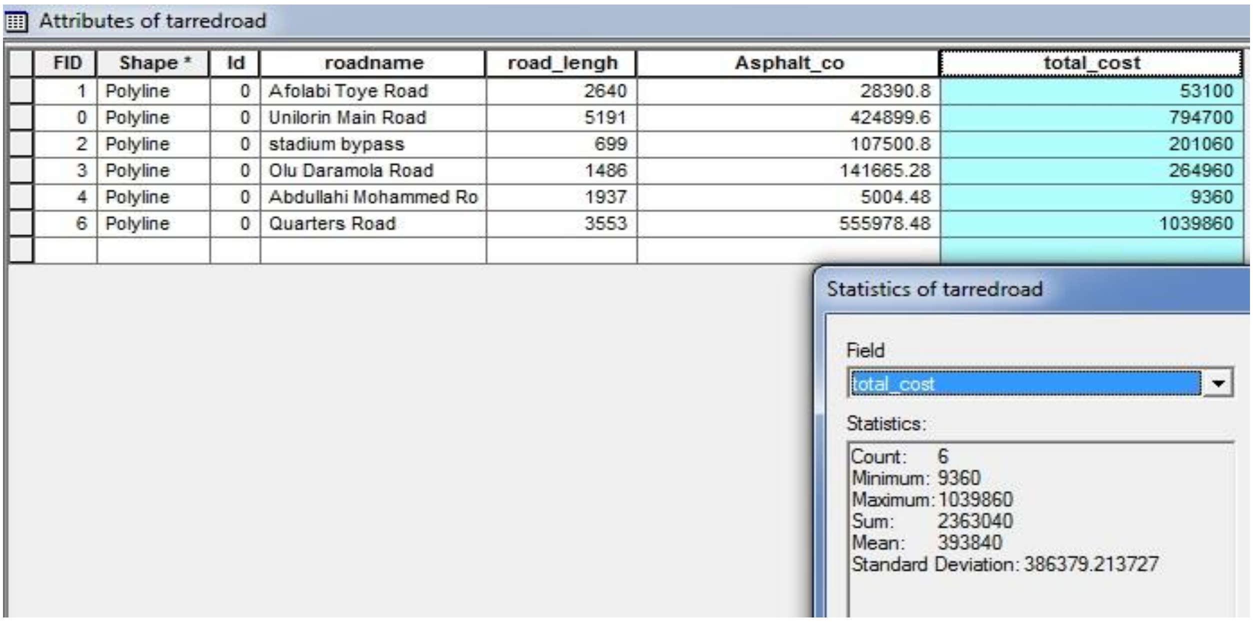


Fig. 7: Pavement condition rating of the road network

5.1.6.2 Query on road budget

The statistical analysis of the budget for each road is shown in Fig. 8 while the graphical display is shown in Fig. 9.



Attributes of tarredroad

FID	Shape *	Id	roadname	road_lengh	Asphalt_co	total_cost
1	Polyline	0	Afolabi Toye Road	2640	28390.8	53100
0	Polyline	0	Unilorin Main Road	5191	424899.6	794700
2	Polyline	0	stadium bypass	699	107500.8	201060
3	Polyline	0	Olu Daramola Road	1486	141665.28	264960
4	Polyline	0	Abdullahi Mohammed Ro	1937	5004.48	9360
6	Polyline	0	Quarters Road	3553	555978.48	1039860

Fig. 8: Statistical analysis for the budget

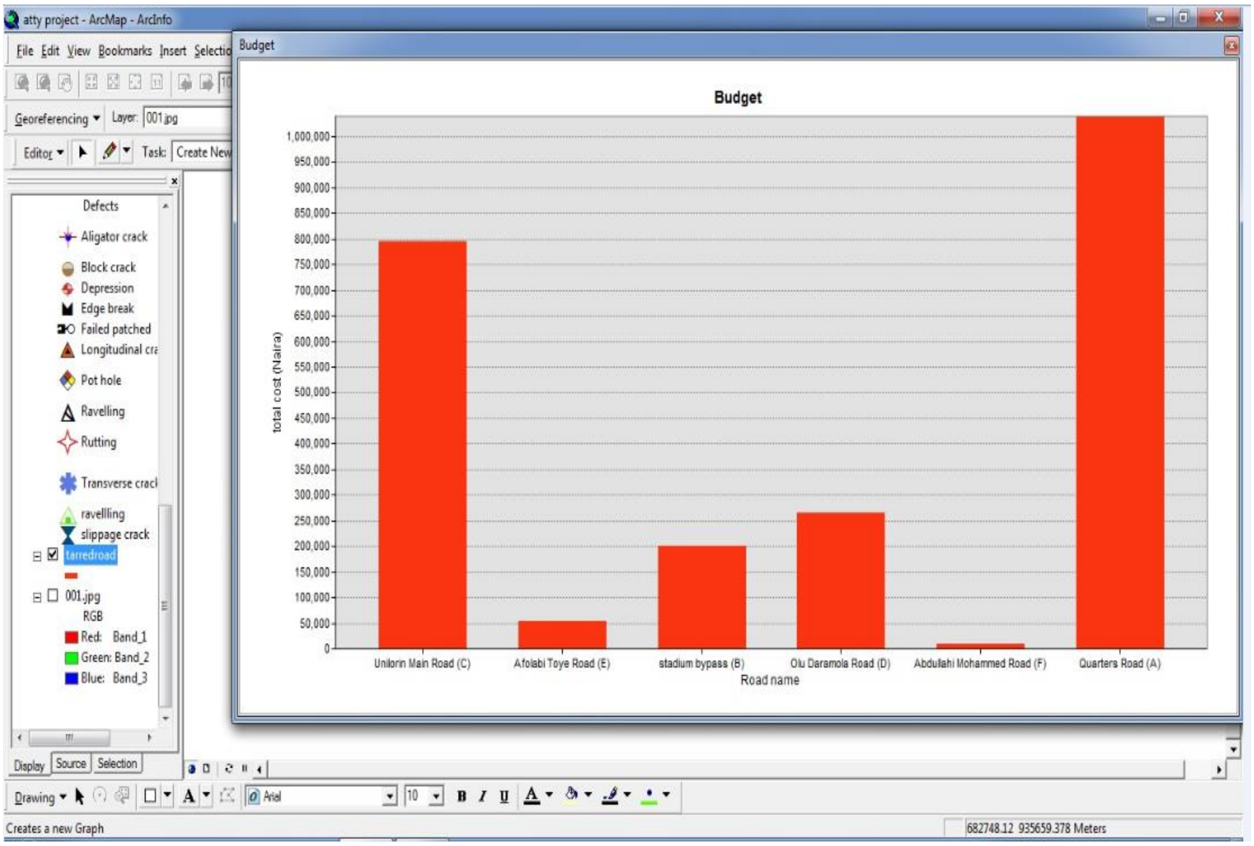


Fig. 9: Budget for each road

5.1.6.2 Simple Query

The database was queried to indicate the roads with budget greater than ₦ 264,960; the result shows the Senior quarter's road and Unilorin main road as seen in Fig. 10.

5.1.6.3 Multiple Queries

The database query to indicate Roads not longer than 1.486km and with Budget less than ₦ 264,960 gave the result as Afolabi Toye road and Abdullahi Mohammed road as shown in Fig. 11.

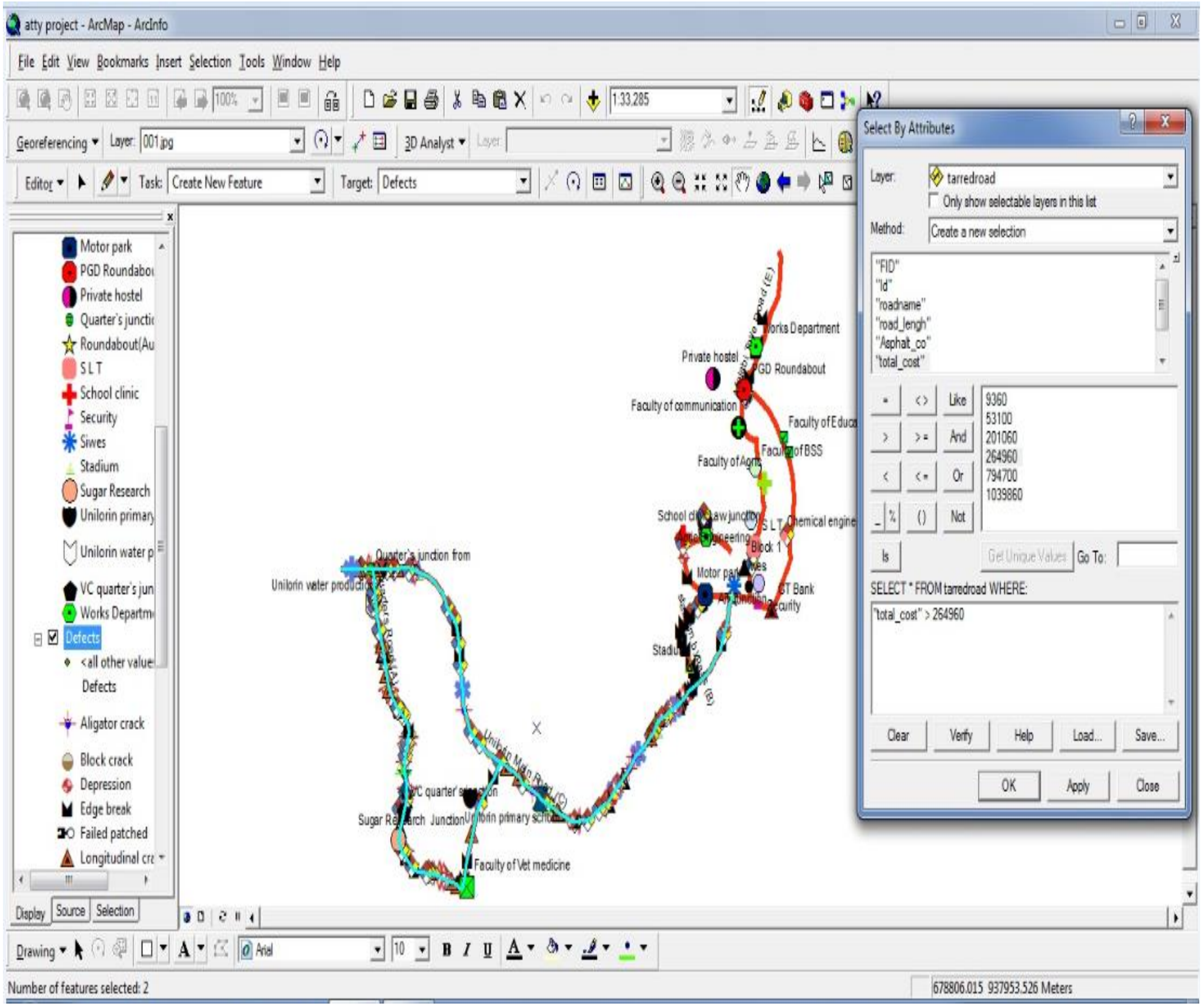


Fig. 10: Simple query of Roads with Budget greater than ₦ 264,960

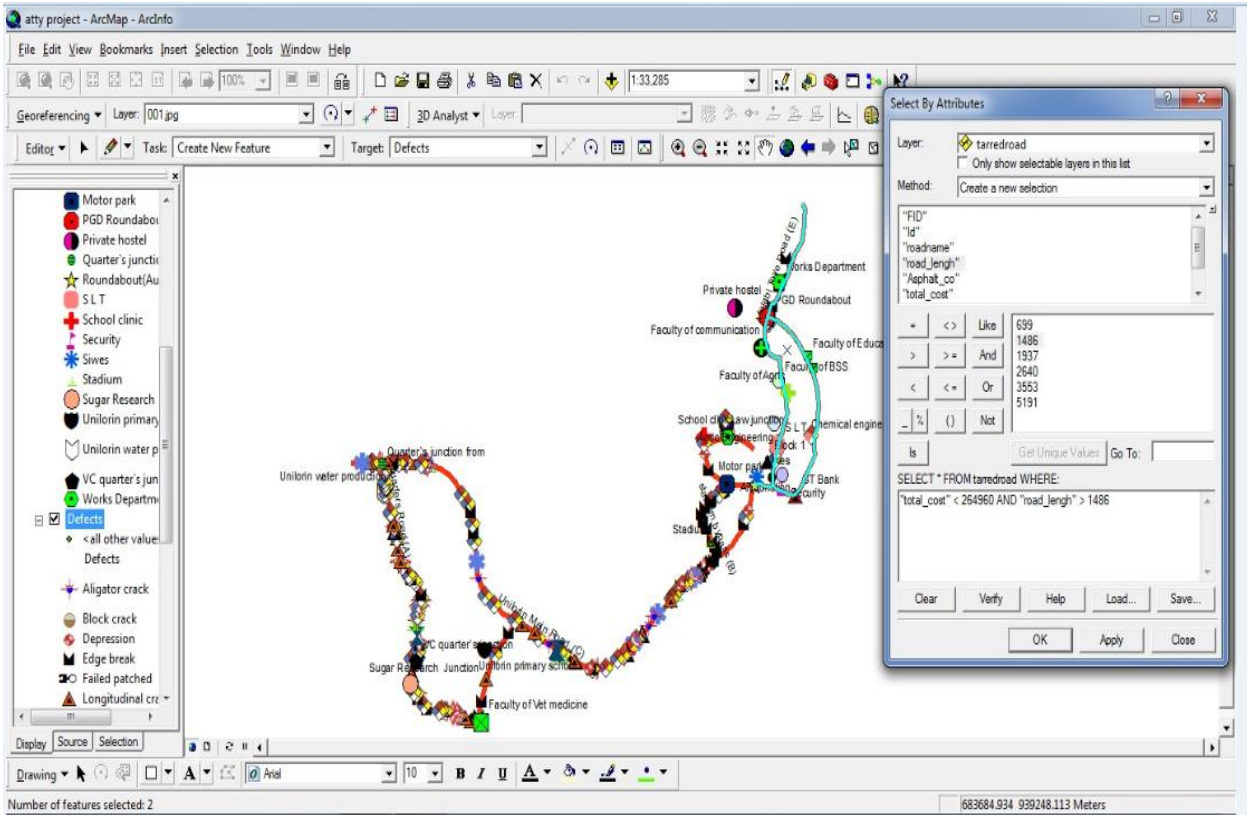


Fig. 11: Multiple query of Roads not longer than 1.486km with Budget less than ₦ 264,960

5.2 Discussion

The results obtained from the analysis of the collected data and the pavement condition rating, gave the level of maintenance required in ascending order as Section A, Section C, Section B, Section D, Section E and Section F. The prepared budgets of each section clearly showed the financial implication of implementing maintenance program. The use of GIS in the management of pavement condition rating data allows for several analyses, queries and both visual and graphical display of information which lend their support to decision making. Through color-coding of pavement defects, the road network condition were displayed which can be viewed and projected for work programs. It displayed and reported the tables and charts showing final information that are necessary for taking cost-effective decision on maintenance strategies and management of the paved roads. Fig. 9 for example easily shows the relative amount needed for the maintenance of each road and can help in prioritising projects. In the case of a large road network such simple and multiple queries as demonstrated in Section 5.1.6.2 and Section 5.1.6.3 can be used for example to assess the locations or geographical spread of the roads that can be maintained within a budget thereby assisting decision makers on maintenance priorities in situation where geographic spread may be a factor in decision making.

6. Conclusion and Recommendation

GIS has been successfully used in the management of pavement condition rating data which is geospatial. The GIS capacity to carry out analyses on the geospatial pavement condition rating data and give visual and graphical display of the results has been demonstrated in the study. GIS thus can be used to build up PMS which will certainly with its attributes serve as a support tool for pavement maintenance strategy selection. Based on this study it is recommended that road maintenance agencies should explore the use of GIS as support tool for pavement management and similar geospatial assets due to its versatility in data analyses, query capability as well as visual and graphical representation.

REFERENCES

Cologrande S., Ranalli D. and Tallini M. (2011). “Ground Penetrating Radar Assessment of Flexible Road Pavement Degradation”, International Journal of Geophysics Vol. 2011, Article ID 989136.

Luz, V. Lagunzad and Kevin McPherson (2003). GIS applications for road network of the Philippines: a new technology in road management. Journal of Eastern Asia Society for Transportation Studies. Vol 5, Oct. 2003. Pp 841 – 854.

Meng L, Yuan J. and Wenial C. (2012). ”Application of GIS in Shanghai Airport Pavement Management System”. Shanghai Airport Authority, Shanghai 200335, P.R. China.

Robert K. (2011). “GIS Based Pavement Maintenance: A Systemic Approach”. College of Technology Directed Projects. Paper 36, Purdue University, West Lafayette, Indiana, USA.

Smadi O. G. (2004). “Quantifying the Benefits of Pavement Management”, 6th International Conference on Managing Pavements, the Lessons, the Challenges, the Way Ahead. Brisbane, Queensland, Australia.

Wisconsin Transportation Information Centre (2002): Asphalt PASER Manual, Transportation Information Centre, University of Wisconsin–Madison, USA

WNCHRP (2004). Web Document 35 (Project C1-38): Contractor’s Final Report Washington, D.C, USA.

WSDOT (1999). “Washington State Highway Pavements: Trends Conditions and Strategic Plan”. WSDOT Field Operation Support Service Center, Materials Laboratory. Olympia, USA.