Analysis of Least Cost Path by Using Geographic Information Systems Network and Multi Criteria Techniques

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***Abstract*– This paper has illustrated how Geographic Information Systems (GIS), Network and multi criteria Analysis (MCA) can be utilized for determining suitable location of routes for Khartoum city, that involved managing a variety of data sets from different sources and at different scales such as: educational, financial, hospitals, business and governmental institutions as well as places of entertainment, it identified as being extremely significance destination points of service for the path and thus established as parameters. Numerous destination points of service were highlighted and categorized under one of the main groups, each main group given a value and weighted against other groups to establish an order of superiority and inferiority. A path between two points was obtained. The start and destination point were selected randomly without any pre-knowledge of the area.**

***Keywords*– GIS, MCA, Analysis and Information Systems Network**

I. INTRODUCTION

Nowadays developing countries face a great challenge in their progress towards modern life. Urban transport has always been viewed as a major factor influencing the quality of life. Khartoum has the highest level of economic activities. Due to an increase in population, as a result of migration from rural areas, traffic congestion and accidents has become a common scene in Khartoum (Fadlalla, 2010).

Traffic congestion along with the problems that stem from it, combine to form, arguably, the greatest dilemma facing city planners. Decreasing this congestion and mitigating related problems is a major priority as the megalopolises of developed nations reach their limits and the metropolises of the developing world burgeon. The establishment of an urban path in one of its many forms has long been a means to mitigate if not solve the traffic problems. However, the construction of urban path is not without its own difficulties.

Minimizing the altering of existing infrastructure; avoiding the razing of residential areas; the impact on the natural environment while ensuring adequate and quality service to the public are only a few of the many issues to be considered when planning a route.

In this paper where the importance of Geographical Information Systems GIS becomes apparent, GIS were integrated with multi criteria analysis which can overcome the dilemmas involved with planning a route. With it, a planner can input any number of parameters to be considered under analysis leading to the most optimal route.

The aim of this study uses GIS, and MCA as an effective tools to create and apply network analysis for Khartoum. It provides a helpful application for finding the optimum least cost path, while using Khartoum, the capital city of Sudan as a case study.

These proposed paths have the potential to provide several advantages, namely the fact that: offers the shortest route possible while linking a considerably large amount of vital utilities along the way with special regard to transportation lines; preserves existing infrastructure including private residences and businesses; follows a course along the existing street layer as much as possible.

II. LITERATURE REVIEW

A study on a selected area in Trabzon situated at the black sea region of Turkey was carried out by Yildirim et al., in 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. This study 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. Spatial analysis in ArcGIS 9.0 was used to create source, generate a thematic cost map, perform cost weighted distance, create direction dataset and perform shortest path with distance and direction datasets.

The weighting rate scheme was used 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. 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 (Yildirim et al, 2006).

III. THE SITE SELECTION

The city of Khartoum is located at the confluence of the White and Blue Niles which combine to form the River Nile. The locality of Khartoum is 405.6 meters above sea level between the (**32°35′31.977"E** and **15°30'6.842"N**) to (**32°28'19.474"E**and**15°37'13.559"N**), the point where the two Niles meet is known as the "**Al-Mogran**". The capital Khartoum contains three metropolitan cities, which is includes the municipalities of Khartoum, Bahry and Omdurman. The state of Khartoum consists seven localities; Khartoum, Bahry, Omdurman, Jebel Awlyia. Sharq Al Neil, Kerary, Um Bedda. This research focuses of the suitability of selection optimum path in the Khartoum locality (Fig. 1). The locality of Khartoum is situated on the south and west bank of the Blue Nile and the east bank of the White Nile with a population of about a **4,229,432** million inhabitants as of 2012.

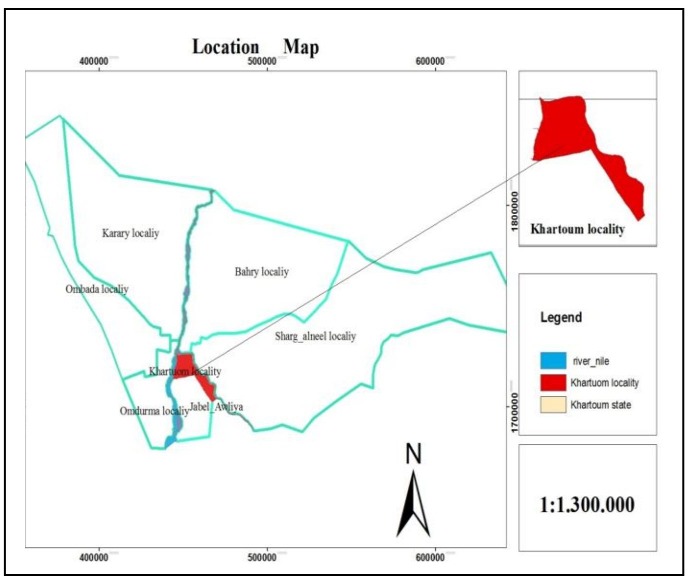

Fig. 1: Study Area

IV. GIS GEODATABASE

The geodatabase was created including thirteen several feature classes streets and vital utilities (Schools, Hospitals, universities, clubs, Hotels, Health centers, Government offices, Sport fields, Transportation stations and Airport) (see Fig. 2). All the Geographic data was referencing to (WGS1984-UTM zone 36 N).

Contents | Preview | Metadata |

Name	Type
Transportaion_station	File Geodatabase Feature Class
streets	File Geodatabase Feature Class
Streetbuffer	File Geodatabase Feature Class
Street_erase	File Geodatabase Feature Class
Squre	File Geodatabase Feature Class
School	File Geodatabase Feature Class
police_center	File Geodatabase Feature Class
Other_Studyarea	File Geodatabase Feature Class
Mosque	File Geodatabase Feature Class
Merge_buffererease	File Geodatabase Feature Class
master_road_ND1_Junctions	File Geodatabase Feature Class
master_road_ND1	File Geodatabase Network Dataset
Markets	File Geodatabase Feature Class
Khartuom_Airport	File Geodatabase Feature Class
Hotel	File Geodatabase Feature Class
Hospital	File Geodatabase Feature Class
High_schooll	File Geodatabase Feature Class
Heilth_center	File Geodatabase Feature Class
Goverment	File Geodatabase Feature Class
Garden	File Geodatabase Feature Class
End_begin	File Geodatabase Feature Class
club	File Geodatabase Feature Class

Fig. 2: The Geodatabase components

The process of digitizing roads to the study area was performed (see Table 1). Road layer was classified to three categories: highway, main road and secondary road. Database was constructed for the query of attribute included road name, maximum design speed, direction of roads and vehicle capacity per hour. Length and travel time according to daily congestion were calculated, all the attribute data for the service layer was added.

Table 1: Street Attribute Data

Attributes of streets

OBJECTID *	SHAPE_Length	FT_MINUTES	TF_MINUTES	METTER	MAX_SPEED	street_name	Normal_timee	ROAD_CAPPACITY	Travel_time	TRAFIC_VOLUME	ROAD_TYPE	CLASS
164	270.333826	0.407393	0.407393	270.333826	40	TAWFEEQ SALEH GEBRIL	0.405501	250	0.407393	105	MS	4
56	325.420458	0.460552	0.460552	325.420458	45	SENKAT STREET	0.433894	1000	0.460552	800	SS	4
154	322.808055	0.661536	0.661536	322.808055	40	SENKAT STREET	0.484212	800	0.661536	1000	SS	6
60	1208.757331	1.879639	1.879639	1208.757331	40	SALEH BASHA STREET	1.813136	1000	1.879639	634	SS	4
67	1119.588006	1.701919	1.701919	1119.588006	40	OSMAN DIGNA STREET	1.679382	938	1.701919	513	SS	4
112	1624.038707	1.964888	1.964888	1624.038707	50	OMMACK STREET	1.948846	2000	1.964888	968	MS	4
7	9230.007454	11.345421	11.345421	10321.030273	60	OBAID KHATEM	10.32103	44000	11.345421	39684	HW	4
118	1113.022441	1.842477	1.842477	1113.022441	40	MOUHMED SALAH ALDEEN STREET	1.669534	2500	1.842477	2279	MS	4
193	6582.871622	11.538961	11.538961	13436.083159	70	MOHAMED MOKHTAR	11.516643	45500	11.538961	15340	HW	2
16	6119.800556	6.129082	6.129082	6119.800556	60	MOBRK ZAROG STREET	6.119601	47250	6.129082	14983	HW	2
53	387.333744	0.582369	0.582369	387.333744	40	MEHERA BNT ABUOD	0.581001	1000	0.582369	354	SS	2
18	4467.493537	5.957296	5.957296	4467.493537	45	MAMON BEHRY STREET	5.956658	2000	5.957296	327	MS	2
195	1744.723626	5.944032	5.944032	3784.049554	40	MAHMUOD SHAREEF STREET	5.676074	2000	5.944032	1498	MS	4
9	10109.156944	11.72508	11.72508	13678.394423	70	MADANI STREET	11.724338	46750	11.72508	6698	HW	2
110	2132.958914	2.635632	2.635632	2132.958914	50	MACKA STREET	2.559551	1250	2.635632	834	MS	4
15	6079.008754	6.081875	6.081875	6079.008754	60	M. NAGEEB STREET	6.079009	37000	6.081875	8761	HW	2
123	940.163901	1.461971	1.461971	940.163901	40	KULYAT ALTIBB	1.410246	1000	1.461971	1237	SS	6
37	878.156786	1.321567	1.321567	878.156786	40	KATREENA STREET	1.317235	1250	1.321567	481	SS	2
119	1630.021422	2.250773	2.250773	1630.021422	50	JUBA STREET	1.956026	3500	2.250773	3504	MS	4
47	2368.844977	2.842917	2.842917	2368.844977	50	IBRAHIM SHAMS ALDEEN	2.842614	1250	2.842917	204	MS	2
36	888.040746	1.332319	1.332319	888.040746	40	IBRAHEEM AHMED KHEER STREET	1.332061	1250	1.332319	237	MS	2
68	1615.281826	2.511792	2.511792	1615.281826	40	HOSPITAL STREET	2.422923	1000	2.511792	1237	SS	6
155	723.157658	1.124523	1.124523	723.157658	40	HASHEM BEY STREET	1.084736	1000	1.124523	1237	SS	6
17	4176.635134	8.505295	8.505295	4176.635134	50	GABRA STREET	5.011962	5000	8.505295	7341	MS	6
23	2385.4614	2.913271	2.913271	2385.4614	50	GABEL AWLYA STREET	2.862554	30750	2.913271	18027	MS	4
19	4188.044707	10.215252	10.215252	8364.511287	50	GABEL AWLYA STREER	10.037414	30750	10.215252	18027	HW	4
186	2247.933906	2.697789	2.697789	2247.933906	50	GABEL AWLYA STREER	2.697521	10000	2.697789	1604	MS	2
49	1179.72644	1.777849	1.777849	1179.72644	40	BYO KWAN STREET	1.76959	2000	1.777849	840	MS	4
181	3522.449204	4.715553	4.715553	3522.449204	45	BURI STREET	4.696599	2000	4.715553	810	MS	4
104	1000.43261	1.200715	1.200715	1000.43261	50	BADR STREET	1.200519	1250	1.200715	227	SS	2
64	881.08837	1.321884	1.321884	881.08837	40	BABEKER BADRY STREET	1.321633	938	1.321884	177	SS	2
69	283.808242	0.441327	0.441327	283.808242	40	ATYAR IZZ ALDEEN STREET	0.425712	1250	0.441327	580	SS	4
26	690.721598	1.037846	1.037846	690.721598	40	ATBARA STREET	1.036082	1250	1.037846	408	SS	2
12	4312.853403	6.660656	6.660656	4312.853403	40	ASAFA STREET	6.46928	1250	6.660656	833	MS	4
188	946.525009	1.262728	1.262728	946.525009	45	ARMY STREET	1.262033	3750	1.262728	923	MS	2
169	157.352811	0.236544	0.236544	157.352811	40	AMOFTI STREET	0.236029	1250	0.236544	434	MS	2
27	2860.429104	4.448018	4.448018	2860.429104	40	ALZABIR BSHA STREET	4.290644	1000	4.448018	555	SS	4
63	590.468668	0.918189	0.918189	590.468668	40	ALTYAR ZULFO STREET	0.885703	1000	0.918189	634	SS	4
62	598.393953	0.930513	0.930513	598.393953	40	ALTYAR IZZ ALDEEN STREET	0.897591	1000	0.930513	634	SS	4
58	1222.46411	1.900953	1.900953	1222.46411	45	ALTYAR GAMEL STREET	1.629952	1000	1.900953	634	SS	4
4	5752.92636	12.554864	12.554864	9387.307022	45	ALTABIA STREET	12.516409	65000	12.554864	24590	HW	2
107	996.665767	1.329218	1.329218	996.665767	45	ALSWAHLY STREET	1.328888	550	1.329218	111	SS	2
128	890.165997	1.189281	1.189281	890.165997	45	ALSOOG ALSHABI	1.186888	2000	1.189281	681	MS	2

Record: 0 Show: All Selected Records (0 out of 178 Selected) Options

V. NETWORK DATA SET

The data was used to create a network dataset based on the street layer in the Network Analyst Extension of ArcGIS 9.3. A network dataset is a representation of a network, in points and lines. In the context of this study the network dataset will represent a street network.

VI. MODEL DESIGNING

The model will be created in the network. Fig. 3 illustrates the model which is used to predict the travel time. The first layer in the model is depicted below; it is the Network Dataset layer. This layer is the base streets layer transformed into a Network. This is done so analysis can be conducted in Network Analyst. The network dataset is created to complete network analysis in network analyst. ESRI has developed the network dataset to represent detailed network models.

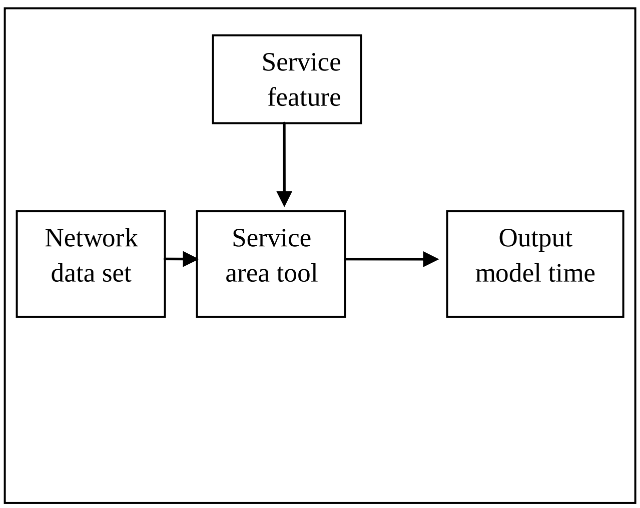

Fig. 3: The Network diagram

The next layer in the model is the service area tool in Network Analyst. This tool is used to find service areas around any location on a network. A network service area is a region that encompasses all accessible streets. For example the 5-minutes service area for a polygon includes all the streets that can be reached within five minutes from that polygon. In this study the service area layers (education, health ….etc) were classified into four period (2, 5, 8, and 10) minutes. The service area layer contains four components, the facilities layer, the polygon layer, lines layer and the barriers layer as in (Fig. 4).

The facilities layer, in this study, includes all the locations which are used as starting points for travel, (education, health, transportation station…. etc) in Khartoum city. The next layer is the barrier layer. This layer is used to include barriers in the street network within the analysis. For example if a street is blocked for construction a barrier would be placed in this location. When the analysis is complete the route would be directed around the barrier. The polygon layer stores the resultant polygons of service area analysis. This is the most important layer in the service area tool it's represent the time ranking. The lines layer can be symbolized in the same manner as other line feature layers.

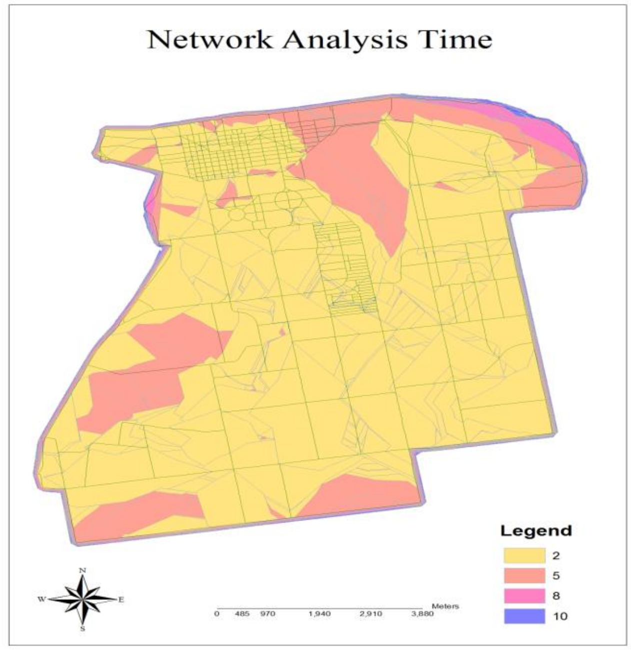

Fig. 4: Network analysis time

VII. MULTI CRITERIA ANALYSIS

Multi criteria analysis is applied and integrates with the spatial data in order to describe the causative factors of a phenomenon under concern. In this study ranking method was used, where every criterion under consideration was ranked in the order of the decision maker's preference and network analysis. To generate criterion values for each evaluation unit, each factor was weighted according to the planer expertise and network analysis time for estimated significance. The inverse ranking was applied to these factors. Factor of rank 2 is the least important and 8 is the most important factor. In the third phase, Pair wise Comparison Method was used to determine the weight of each criterion.

VIII. CREATION OF SCRIPT

Technical problem arise when convert the service layers to raster. The intersection between the service layers provide false pixel value in the overlap area, Due to that the script was developed to convert each layer separately and collected again with a correct pixel values. The script was created below the toolboxes within the Arc toolbox. Thirteen weight images were provided based on service data, and categorized to four classes (educational, health, general service and tourism) as indicated in the Table 2.

IX. PAIR WISE COMPARISON METHOD

This method involved the comparison of the criteria and allows the comparison of two criteria in the same time. It can convert subjective assessments of relative importance into a linear set of weights.

X. SUB-LAYER WEIGHT

The square pair-wise comparison matrix was generated for the sub-layers each factor was weighted according to the estimated significance importance as shown in (Table 2). The Map algebra tool in ARCGIS 9.3 was used to merge the thirteen sub-layers based on weights of sub layer (after classification into-groups) to form four main layers.

XI. MAIN LAYER WEIGHTS

The square pair-wise comparison matrix was generated for a main-layer each factor was weighted see (Table 3).The normalized matrix is presented in (Table 4) Meanwhile, the individual judgment, which never agreed perfectly with the degree of consistency achieved in the ratings, was measured by using Consistency Ratio (CR), indicating the probability that the matrix ratings were randomly generated. The Random Indices for matrices are listed in (Table 5). The rule of thumb is that a CR less than or equal to 0.1 indicates an acceptable reciprocal matrix, while a ratio over 0.1 indicates that the matrix should be revised**.**

Table 2: layer weights

Number	Main layers	Sub layer	Raster Weigh
1.	General service	Government	0.471023483
2.		Transportation	0.329494372
3.		Airport	0.073839321
4.		Police	0.125642824
5.	Tourism	square	0.075436096
6.		Garden	0.07576119
7.		Market	0.3638022
8.		Hotel	0.37865104
9.		Club	0.106349474
10.	Education	School	0.26454
11.		University	0.6753891
12.	Health	Hospital	0.543422
13.		Health center	0.329332

Table 3: The comparison probability

	Tourism	Health	Education	General service
Tourism	**1**	**0.2**	**0.2**	**1**
Health	**5**	**1**	**0.25**	**4**
Education	**5**	**4**	**1**	**5**
General service	**1**	**0.25**	**0.2**	**1**

Calculating Consistency Ratio (CR)

CR= CI/RI Where CI= λ_{max}-n/n-1

RI = Random Consistency Index

n = Number of Criteria

λ max is the priority vector multiplied by each column total, λ max= 4.216396

CI = 0.072132

CR = 0.080147

Table 4: Four layer weights

	Tourism	**Health**	**Education**	**General service**	**Sum**	**Weights**
Tourism	0.083333	0.036697	0.121212	0.090909	0.332152	0.083037948
Health	0.416667	0.183486	0.151515	0.363636	1.115304	0.278826105
Education	0.416667	0.733945	0.606061	0.454545	2.211218	0.55280442
General service	0.083333	0.045872	0.121212	0.090909	0.341326	0.085331526

Table 5: Shown the Random indices for matrices of various sizes

N	R1
1	0
2	0
3	0.58
4	0.9
5	1.12
6	1.24
7	1.32
8	1.41
9	1.45
10	1.49
11	1.51
12	1.48
13	1.56
14	1.57
15	1.59

Fig. 4 illustrates merging process. Raster calculator was used to form the suitability map combined the four main layers (educational, health, general service and tourism). The street layer was integrated into the analysis in order to ensure that the suggested path and street layer would coincide together in order to avoid razing, the infrastructure and resident regions, the route layer was converted to raster based on the value of traffic volume which was calculated by using the BPR equation.

The final suitability map was produced based on the four service layers and the raster street layer as shown in Fig. 6.

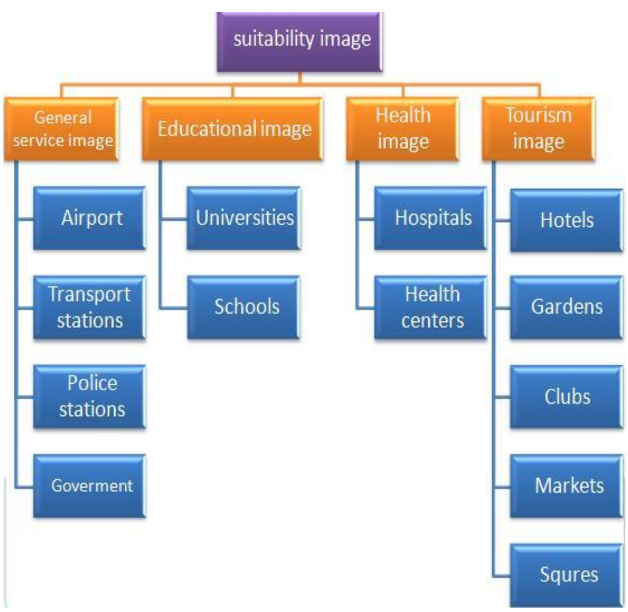

Fig. 5: Data combination

XII. DETERMINE THE PATH

To create a path 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 suitability image that indicates the cells from which cost should be determined. The new shape files contain start and destination points for the road path was created using Arc Catalog 9.3 (Fig. 7) and the cost-weighted path (direction and allocation) were calculated. This is to ensure that the route points created within minimum cost cell under study area. Table 6 indicates the approximate coordinates for the start point and destination point.

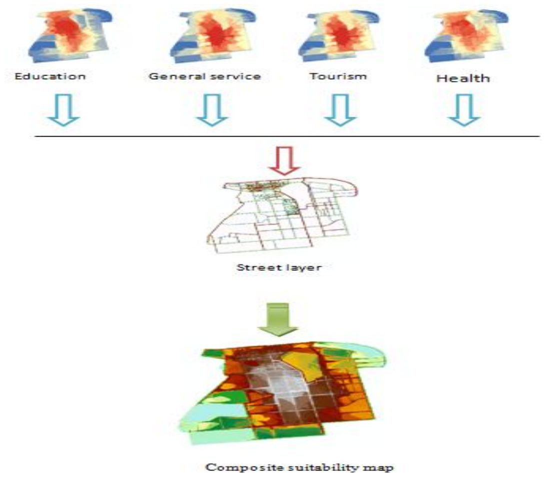

Fig. 6: Aggregation of suitability maps

Table 6: The coordinate of starts and destination points

OID	Name	Path Description	Easting	Northing
.1	R1	The First path	450038.5605	1725677.395
.2	R2		452793.264	1715858.094
.3	G1	The Second path	446197.9022	1718587.465
.4	G2		455591.4914	1724578.253

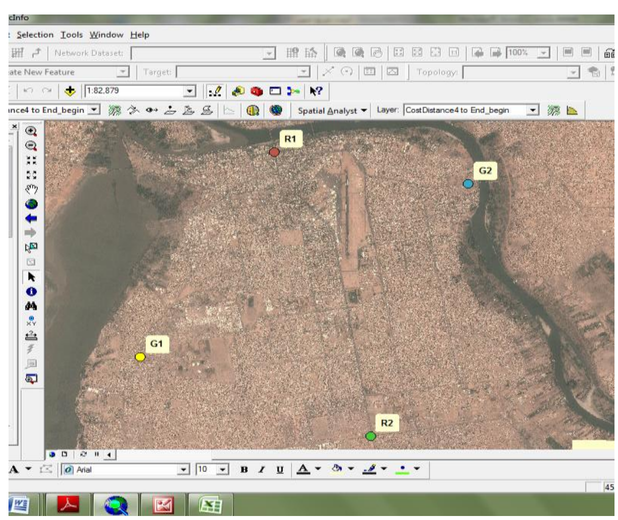

Fig. 7: Starts and destination point for two paths selecting short path tool

XIII. DISCUSSION AND RESULT

The purpose of this paper was to introduce the applicability of geographic information system (GIS) and Multi-criteria analysis (MCA) to identify a least cost path between two points using the Khartoum locality as a case study. The use of (GIS) helped to incorporate digital layers of different scales. Planning a route path is complex and presents a number of challenges. The level of the complexity in the planning process comes from the consideration of different factors, which must be considered in the analysis. In order to minimize environmental impacts and to achieve sustainable development in the determination of a route path, it is essential to determine the relative importance of the considered parameters.

Thus there are two paths resulting according to this study (path A and path B) and to in identifying the advantages and disadvantages of each route, it is necessary to restate the four-mentioned criteria of an optimum route through the Khartoum metropolitan area. It can be said that an optimum route is one that: offers the shortest route possible while linking a considerably large amount of vital utilities along the way with special regard to transportation lines; preserves existing infrastructure follows a course along the existing street layer as much as possible, Indeed route A has many advantages while having few disadvantages. The primary advantage of Route A is that it starts from the central bus station of Khartoum thereby linking bus routes from various regions of the tri-city area. Furthermore, it goes as far as the Khartoum Land Terminal thus the path links local transportation lines with interstate transportation lines.

This route serves well, numerous amounts of medical, educational, financial institutions as well as the airport. And also it goes along the existing street layer, and as a result, the construction of it would minimize the need to raze infrastructure and residences. Contrastingly, it could be argued that Route A does not adequately serve governmental ministries; it fails to link with other vital roads like Mohamed Najeeb Street. In regards to Route B, there are two noticeable advantages. The first being that, it travels through several major residential areas (Al Mab, Al Remala, Al Diem) of Khartoum along the existing street layer. Thus, potentially, giving access to a large segment of the population. Secondly, Route B intersects with several major roads (Jebel Awlyia Street, Al Sajana Street, SahafaZalat, M. Najib, Africa Street, ObaidKhatim and Nefiedi Street) thereby linking it to a number of bus routes. However, the disadvantages of Route B are that it is quite long in terms of distance which, could lead to an increased cost expenditure.

Moreover, it does not serve a significant amount of high priority locations like Khartoum University. In comparing the two routes, it can clearly be seen that Route A is the most optimum rout. Firstly, Route A is 11,295m and Route B is more than 14,000m long,while clearly serving a greater number of vital utilities than Route B. Route A begins at the the central bus station and ends at the Land Terminal for innter-state travel while along the route there are a deferent services. Moreover Route A more closely follows the existing street layer, thereby reducing the need to alter the landscape of infrastructure and other buildings. Although Route A is the most suitable of the two routes if only one were to be selected, the use of two routes together provides to the most ideal situation in that a sort of network is created reaching the largest area.

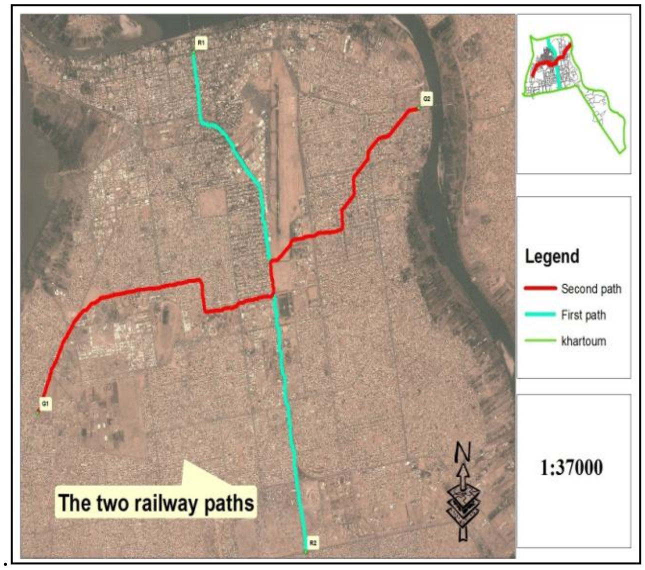

Fig. 8: Two route paths

XIV. CONCLUSION

Ultimately, the final result obtained in this study supports other researches in the application of GIS and MCA in complex planning. The result has demonstrated the applicability of GIS and MCA principles and techniques identifying a route path while avoiding the rigors of route planning using the traditional method. The possibility of using GIS and Multi criteria analysis in complex planning processes in Khartoum has been successfully shown in this paper. GIS and MCA can not only be used in route planning but also in the planning processes of other projects such as airports and industrial areas.

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