Geospatial Approach to Route Optimisation for Security Architecture Improvement

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Understanding the complexity of road networks is tiring, especially in finding the optimum routes for emergency response. Dynamic route optimisation is a decision-making process powered by mathematical models to formulate a strong basis for predicting the best path between any two points in a road network. Exploring the numerous interconnected routes in and out of a road network provides a strong foothold for securing lives and properties. This study presents the findings of route optimisation at the Federal University of Technology Minna, Gidan Kwano Campus. High Target Differential Global Positioning System receiver (DGPS), Handheld GPS (Garmin GPSmap 60Cx), Quick Bird Satellite Imagery, and Google Earth Images were used for data acquisition purposes. An ArcGIS network analyst for optimum route identification based on Dijktra's algorithm was utilised for analysis. Five different optimisation tests were done and the optimised routes were compared with alternative routes from the network. The total travel distances for alternative and optimum routes are 11852.414 m and 16614.156 m respectively while the total travel times for alternative and optimum routes are 2135.35 s and 2993.25 s respectively. The study revealed all optimum routes are faster cumulatively by (11.7%) and are best for security and emergency responses. Ten unauthorised access roads to the campus were identified. The number of routes paving access to the campus shows that efforts towards ensuring security must be increased.
Keywords: Route optimisation, ArcGIS network, security system, road network

INTRODUCTION

A road network is several interconnected lines and points representing a system of roads in a given area. Identifying the best route between any two locations in the network is pertinent today and has formed a basis for route optimisation (Obafemi, 2011). Route optimisation refers to the process of finding the most efficient route for a given set of destinations. In the context of security systems, route optimisation is useful for improving the effectiveness of security patrols and emergency response (Dewinter *et al.,* 2020). Security systems are designed to protect people, property and assets from harm or theft. Hence, these systems also give room for health emergencies and fire outbreaks. Route optimisation increases the efficiency of security personnel to cover more ground in less time, reducing the risk of incidents going undetected (Zafar *et al.,* 2011). Geographic information system (GIS) is a valuable tool for handling and analysing such complex spatial data (Dimitriu, 2007). GIS network analysis is frequently used to identify fresh approaches to transportation issues. One of the main uses for this kind of analysis is in transportation planning, where the challenge is to find the best routes that satisfy a set of requirements, such as finding the optimum route between two or more locations or identifying all areas that fall within a given criterion (Rotaru *et al*., 2018; 2014).

Route optimisation in this study utilised geospatial techniques to define the best routes between two locations, the distance between them, road conditions and mapping all the routes that pave the entrance to the Federal University of Technology Gidan Kwano campus, including footpaths. It involves developing a GIS model to optimise the road network in the campus and then testing different routes from source to destination within the campus (senate building, hostels, staff quarters and clinic) for emergency response and security purposes.

This study presents the findings of route optimisation at the Federal University of Technology Minna, Gidan Kwano Campus using High Target Differential Global Positioning System receiver (DGPS), Handheld GPS (Garmin GPSmap 60Cx), Quick Bird Satellite Imagery, and Google Earth Images. ArcGIS network analyst for optimum route identification based on Dijktra's algorithm was utilised for analysis. Section 2 outlines the study area. Different sources of data utilized in the research is presented in Section 3.1, while the methodology used in the research and the results are discussed in Section 3.2 and Section 4.0 respectively. The study's findings and conclusions are summarized in Section 5.

STUDY AREA

The Gidan Kwano Campus of the Federal University of Technology, Minna, is found along the Minna-Bida expressway. It is approximately 12 km from the main town (Minna) and lies between 9^0 31'41" N and $9^0$32'13" N of Latitude, and $6^0$26'19" E and $6^0$27'59" E of Longitude. It also covers an area of approximately 10km^2 (See Figure 1).

The region falls inside the Guinea savannah vegetation, involving different types of vegetation and

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high woodland plants along the streams and depressions. There are two seasons experienced in the region: the wet and dry seasons.

The general yearly rainfall in the study area is approximately 1086 mm and 1309 mm, typically experienced in the months of April to November. The average recorded temperature of the study area ranges between 32^0C and 33^0C. The highest measure of precipitation is recorded in August. The daytime temperature at its peak is approximately 35°C in March and April, while a temperature of approximately 24°C is the lowest temperature recorded in December and January (Ibrahim, 2014).

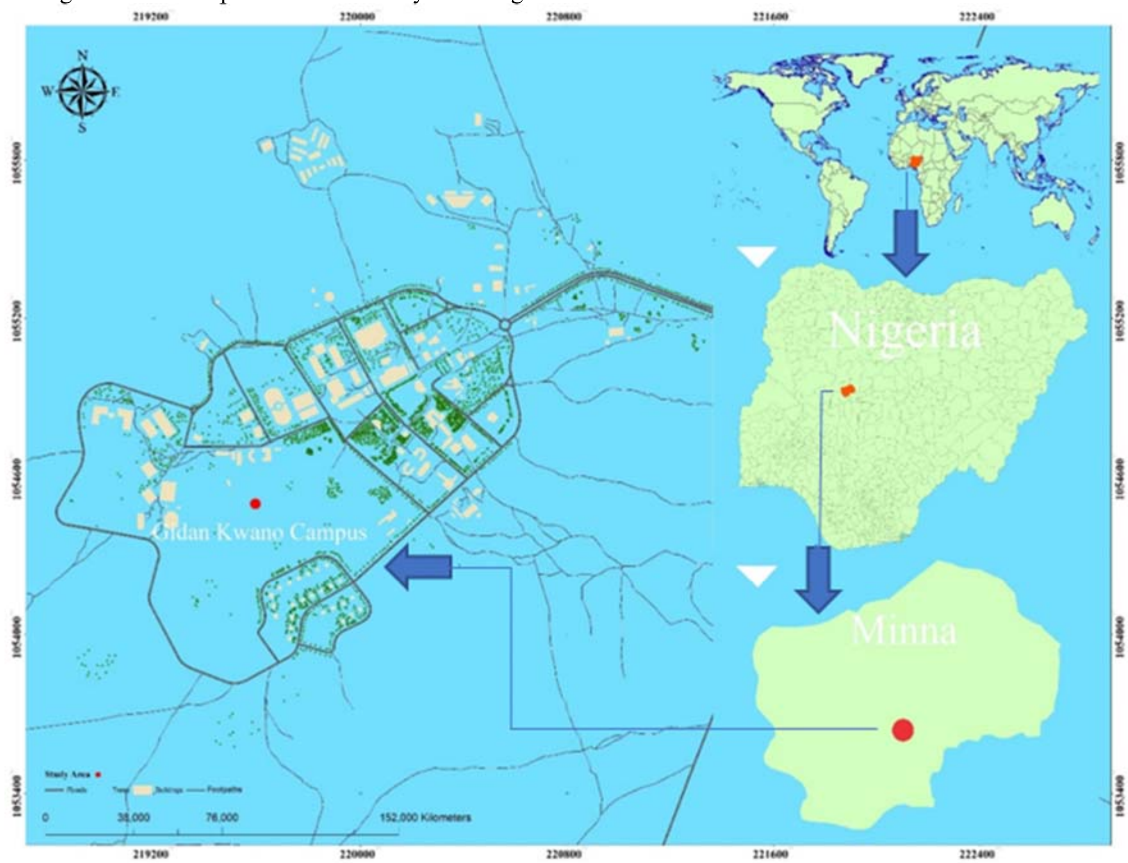

Figure 1: Study Area (Source: Authors Laboratory work)

MATERIALS AND METHODS

The type of data required for this study was the determinant of the instrumentation employed for data acquisition. Figure 2.0 displays an overview of workflow sequence, methods and data types used at every stage.

Materials

The instruments used and datasets are as follows:

- High Target Differential Global Positioning System receiver (DGPS)
- Handheld GPS (Garmin GPSmap 60Cx)
- Quick Bird Satellite Imagery
- Google Earth Images

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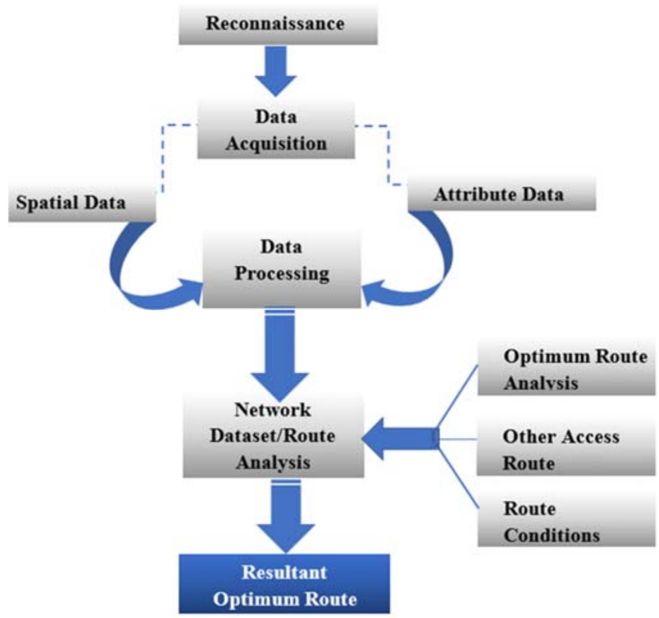

Figure 2: Workflow diagram

The data collection process for this study was in various stages and methods according to geospatial principles tailored toward achieving the aim and objectives of the study. The following methods were employed to acquire all the necessary data.
a) Collecting existing datasets
b) Ground surveying using High Target DGPS
c) Detailing using Handheld GPS (Garmin GPSmap 60Cx)

Methods

Coordinates for the ground control points needed (GPS09 FUT & GPS08 FUT) were directly collected from the GIS Laboratory surveying department of FUT Minna. Quick Bird satellite imagery of 0.5 m spatial resolution was also collected from the same GIS Laboratory. Google Earth Imagery was downloaded with HD quality.
A High Target Differential Global Positioning System receiver (DGPS) was configured for the RTK (Real Time Kinematics) survey mode using two sets of control points (GPS09 FUT & GPS08 FUT). The centreline of the road network was picked on a straight line and at every curve and turning points at 10-second intervals along with features by the roadside. Features and facilities within the campus were captured using hand-held GPS for the purpose of geotagging attributes. Most of these features were picked as point data, while some were captured as polygons.
The Quick Bird Satellite Imagery image dataset was subjected to standard image processing, which includes radiometric corrections and atmospheric corrections. The image dataset by Google Earth was downloaded in HD format such that one scene covered the whole area. These images were georeferenced.
Processed GPS data were carefully arranged in CSV formats and exported into a personal geodatabase folder created in the ArcGIS environment. A rapid plotting technique was adopted via the display X, Y data tool. The centre line of the roads appeared as point data and hence were interconnected by digitising tools to form the road network. The same tool was also used to add features to the network as captured by the images, thereby mapping the whole area, including footpaths.
Route network analyst in ArcGIS was engaged to optimise the network dataset that was created. The origin-destination (OD) cost matrix is also excellent for some reasons; it is efficient for planning traffic, management and control (Bonnel *et al.,* 2015). It can solve the least-cost paths along the network from multiple origins to multiple destinations (Rotaru *et al*., 2018). It is also profound in modelling the distribution of travel demand spatiotemporally among other algorithms (Osorio, 2019; Zhi, 2023).
Route analysis, which is based on the popular Dijkstra algorithm, was adopted because the study is centred on a single-source to a single-destination optimum route problem (Dijkstra, 1959; Ekowicaksono *et al*., 2016).

Dijkstra Algorithm

Dijkstra algorithm represents a road network by a graph. The algorithm is based on the idea of maintaining a set of visited nodes and a set of unvisited nodes.

In a road network N = (V, E) _ _ _ _ _ _ _ _ __ _ _ _ *eqn (1)*

V is the set of nodes and E is the set of edges connecting the nodes. Each edge e in E has an associated non-negative weight w(e) that represents the cost of traversing that edge.

*D[source] = 0, D[i] = infinity for all i ≠ source*_ _ _ _*equ (2)*

Where D is an array of distances and D[i] is the shortest known distance from the source node to node

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i. All distances are set to infinity, except for the source node, whose distance is set to zero (Dijkstra, 1959). The algorithm selects and records as visited the unvisited node with the shortest distance value in the distance array at each iteration. If a shorter path is discovered through the selected node, the method updates the distance value for each unvisited neighbor of the selected node in the distance array. In particular, the distance value of n is updated to the new distance value for a neighbor n of the chosen node i if the distance from the source node to i plus the weight of the edge (i,n) is less than the existing distance value of n.

The target node is marked as visited or there are no more unvisited nodes with finite distance values, the method iterates continuously. At termination, the distance array contains the shortest path distances from the source node to all nodes in the network (Singh, 2018)

Optimum Route Determination

The network dataset was subjected to some parameters for analysis, stops were added, and barrier categories for line and polygon barriers, time and distance were configured by creating fields for them in the attribute table. The table contains the travel time, travel distance, and road names and road conditions. Travel time was calculated using field calculator thus;

Time = $\frac{Distance}{Speed}$ where an expected speed of 20km^{-1} was utilized.

Likewise, U-Turns are permitted all over the network. The straight lines on the map are output from the network analyst, but the network distance between origins and destinations is represented by the values recorded in the line attribute table.

To arrive at the optimum routes for smooth security operations within the Federal University of Technology Gidan Kwano Campus, an ArcGIS network analyst was utilised (Silalahi *et al.,* 2020). Five routes leading to Five different vital locations on the campus gate were considered for analysis. In each case, a new route was created in ArcGIS Network Analyst to have an origin leading to a selected location. The selected locations are Senate building, Clinic and Student Hostel and the staff quarters. The travel time and distance for each of these routes were calculated and compared with those of the alternative routes.

RESULTS AND DISCUSSION

A digital road network map of the Gidan Kwano Campus, Federal University of Technology, is an offline vectored map modelled with the ArcGIS network analyst to perform dynamic route optimisation per time by calculating the best route between any two points throughout the network. Figure 3 shows the optimum route from the campus gate to the school clinic, which is 147.442 m shorter than the alternate route, as shown in Table 1. This implies that the travel time to cover the optimum route is less, which is important during emergency health circumstances for life security (see Table 2). Figure 3 also reveals that the optimum route from the campus gate to the senate building is 226.307 m shorter than the alternative route. By implication, the optimum route is to be used for emergency responses.

Figure 3: Optimum Route versus Alternative Route from Campus Gate to school Clinic

Likewise, Figure 4 reveals that the optimum route is also shorter than the alternative, with 297.849 m when calculated from the campus gate to the student hostel, among others. Figure 5.0 also displays the optimum route and the alternative from the campus gate to staff quarters and table 1.0 confirms that the optimum route is shorter by 851.778 m, likewise it has a shorter travel time as seen in Table 2. Optimum routes from the staff quarter to the school clinic is displayed in Figure 6 and has a shorter distance and travel time as seen in Tables 1 and 2 respectively. As shown in Figure 7, using the optimum routes are faster and can be best for curbing criminal activities on the campus and for planning cost-effective security patrols. The result reveals that the optimum route between any two locations on the map can be calculated offline and proves that the optimum routes are better; hence, judging a route by mere eyes is not scientific. Result shown in Figure 8 identifies ten (10) different routes paving the entrance to the campus environment apart from the school gate. These routes are motorable; they are unconstructed routes but create an entrance to the campus environment. These routes connect the campus with various villages and settlements around the vicinity. By implications, it will be difficult to control unauthorised access to the campus, crime, hawking,

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emergency responses, hereby leading to insecurity. According to Ihechu *et al.* (2023), insecurity negatively affects assessments in universities.

Figure 4: Optimum Route versus Alternative Route from Campus Gate to Senate Building

Figure 5: Optimum Route versus Alternative Route from Campus Gate to Student Hostels

Figure 6: Optimum Route versus Alternative Route from Staff Quarters to school Clinic

Figure 7: Optimum Route versus Alternative Route from Staff Quarters to school Clinic

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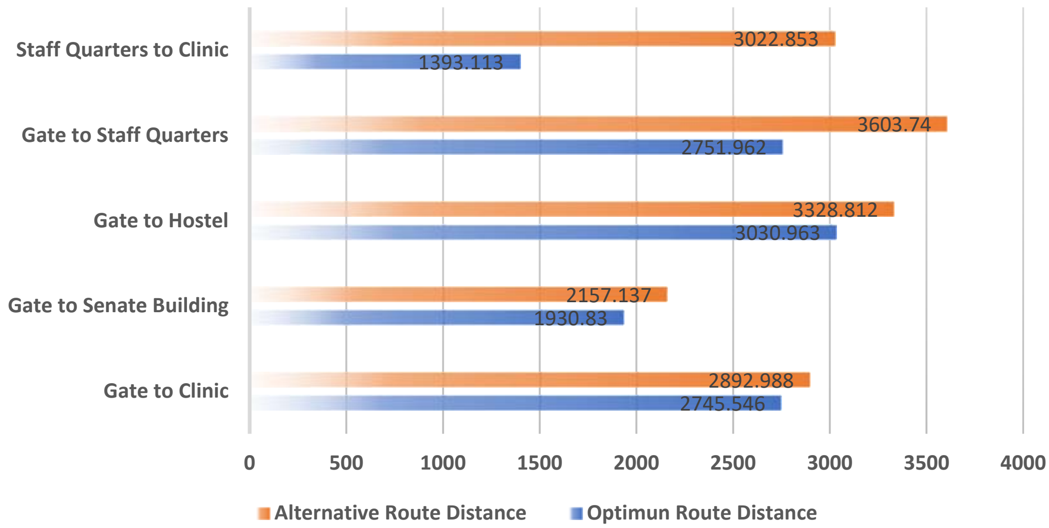

Figure 8: Bar chart comparing the optimum routes and alternative routes

Table 1: Comparison of distances between optimum routes and alternative routes

Origin-Destination	**Optimum route distance (m)**	**Alternative route distance (m)**	**Difference in distances (m)**	**Remark**
Gate to Clinic	2745.546	2892.988	147.442	The optimum route from source to destination is efficient by 4.67%.
Gate to Senate Building	1930.830	2157.137	226.307	The optimum route is the shorter to the destination by 7.17%.
Gate to Student Hostel	3030.963	3328.812	297.849	The optimum route from source to destination is efficient by 9.44%.
Gate to Staff Qua	2751.962	3603.74	851.778	The optimum route is the shorter to the destination by 27.01%.
Staff Quarters to Clinic	1393.113	3022.853	1629.740	The optimum route from source to destination is efficient by 51.68%.
Total	**11852.414**	**15005.53**	**3153.116**	**Optimum route efficiency (11.7%).**

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Table 2: Comparison of travel time between optimum routes and alternative routes

Origin-Destination	Travel time for Optimum route (s)	Travel time for Alternative route (s)	Difference in Travel time (s)	Remark
Gate to Clinic	494.64	521.22	26.58	The optimum route has a lesser travel time by 3.1%.
Gate to Senate Building	347.88	388.62	40.74	The optimum route has a lesser travel time by 4.7%.
Gate to Student Hostel	546.06	599.76	53.70	The optimum route has a lesser travel time by 6.2%.
Gate to Staff Quarters	495.79	649.25	153.46	The optimum route has a lesser travel time 51.6%.
Staff Quarters to Clinic	250.98	544.59	293.61	The optimum route has a lesser travel time 34.2%.
Total	**2135.35**	**2703.44**	**567.48**	**Optimum route efficiency (11.7%)**

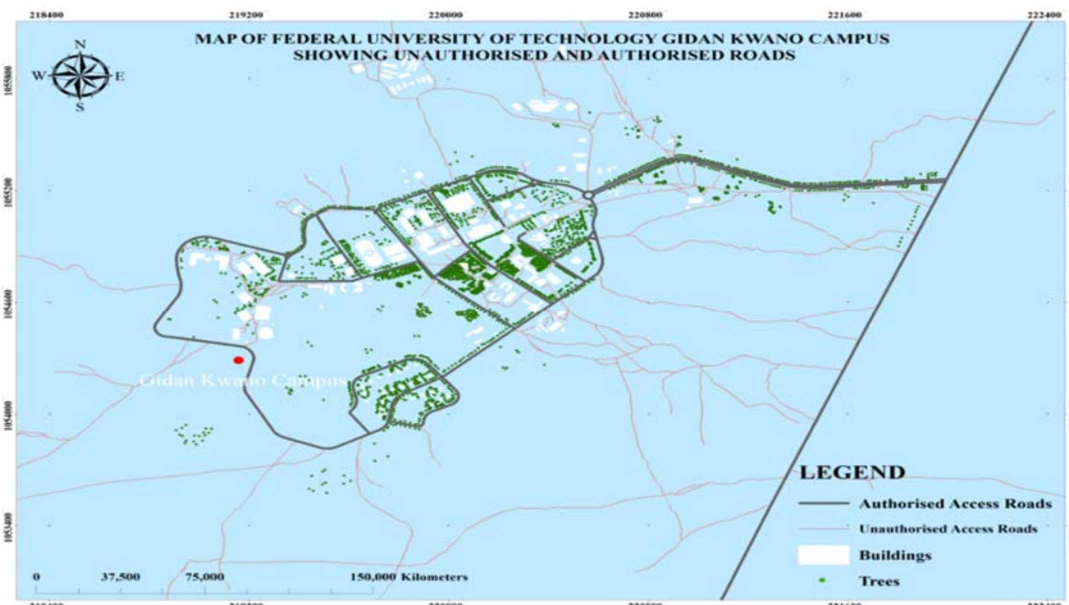

Figure 9: Other routes paving entrance to the campus apart from the gate

CONCLUSION AND RECOMMENDATION

In this study, the dynamic route optimisation for security system in Federal University of Technology, Minna, Nigeria was determined. This study integrated the ground survey data of the Gidan Kwano campus road network into the GIS environment, thereby highlighting the application of GIS in route analysis to determine optimum routes. Using mere eyes to assume the optimum route is not scientific and does not lead to accurate results. From the ArcGIS digital map produced, the optimum route to locate any feature on the campus between any two locations can be computed offline using the ArcGIS network analyst for route optimisation. Knowing and using the optimum routes is useful for curbing criminals, fighting fire and health emergencies within the shortest time to secure lives and property. The map has also identified ten (10) other routes apart from the school gate paving entrance to the campus environment, see figure 8.0. This implies that unwanted activities such as hawking, theft, insurgence, etc., can be controlled effectively if these entrances can be properly monitored. thereby strengthening the security system of the campus. Different situations make road users seek optimum routes, including security patrols for curbing criminal activities and emergencies responses to save lives, time and resources. GIS is a tool capable of accurate decision-making in such circumstances and beyond. This has been demonstrated in this study.

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