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GEOSPATIAL OPTIMIZATION OF EMERGENCY RESPONSE ROUTES USING GIS AND DIJKSTRA'S ALGORITHM: A CASE STUDY OF UNIVERSITY OF BENIN TEACHING HOSPITAL, NIGERIA

[1]Godsent Efosa Felix, [2]Uchenna Ukeme and *[1]Stephen Olushola Oladosu

[1]Department of Geomatics, Faculty of Environmental Sciences, University of Benin, P.M.B. 1154, Edo State, Nigeria.
[2]Department of Civil Engineering, Faculty of Engineering, University of Benin, P.M.B. 1154, Edo State, Nigeria.

*Corresponding authors' email: olushola.oladosu@uniben.edu Phone: +2348065211810

ABSTRACT

Emergency response times are critical in determining patient outcomes in urban healthcare settings. The University of Benin Teaching Hospital (UBTH) serves a densely populated region of Benin City, Nigeria, where efficient route planning is essential for rapid medical intervention. This study employs Geospatial Information System (GIS) tools and Dijkstra's algorithm to analyze and optimize emergency routes within a 6.5 km catchment area of UBTH. Road network data, population density, and service areas were integrated into a spatial database and analyzed using ArcGIS 10.8. The shortest travel paths and times from various strategic locations, including New Benin Market, Egor Market, Evbuotubu, Ziko Gas, and National Museum, were computed. Results show that New Benin Market provides the shortest access to UBTH at 5.2 km in approximately 8 minutes, while Ziko Gas yielded the longest route at 8.5 km in 13 minutes. These findings show the critical role of geospatial technologies in improving emergency healthcare delivery and minimizing patient morbidity and mortality rates through timely interventions.

Keywords: Accessibility, Dijkstra Algorithm, GNSS, Health Centre, Planning

INTRODUCTION

Access to timely and efficient emergency healthcare is a critical determinant of health outcomes, particularly in urban and densely populated regions (World Health Organization, 2025). In Nigeria, tertiary healthcare facilities such as the University of Benin Teaching Hospital (UBTH) play a central role in providing specialized medical services to a wide population (Ogboghodo et al., 2021). However, the effectiveness of such institutions can be significantly hindered by the absence of optimized emergency response routes (Abah, 2023). In many urban centers, including Benin City, traffic congestion, poor road conditions, and lack of dynamic route planning impede timely medical interventions, potentially resulting in preventable morbidity and mortality (Obaseki et al., 2021; McGrail et al., 2015).

Traditionally, emergency routing decisions have relied on the experiential knowledge of ambulance drivers or on basic static maps that fail to consider real-time variables such as road length, closures, or changing traffic conditions. These traditional methods are limited in scope and offer minimal precision in route selection (Katsuma & Yoshida, 2018). In contrast, advances in geospatial technology offer promising solutions to this challenge. Geographic Information Systems (GIS) provide tools that allow the visualization, analysis, and interpretation of spatial data related to roads, traffic, healthcare infrastructure, and population distribution (Cromley & McLafferty, 2011). GIS enables researchers and planners to assess healthcare access within geographic contexts, uncover spatial disparities, and simulate various intervention scenarios including internet of things (IoT) services (Ayesha & Chakravarthi, 2023a; Ayesha & Chakravarthi, 2023b).

Geospatial technologies, specifically Geographic Information Systems (GIS), have emerged as transformative tools in emergency response planning and healthcare logistics. GIS facilitates the collection, storage, visualization, and analysis of spatial data, enabling stakeholders to make data-driven decisions concerning health facility accessibility and service delivery (Cromley & McLafferty, 2011; Skinner, 2010). One of the most important applications of GIS in emergency planning is the determination of optimal routes using shortest-path algorithms, particularly Dijkstra's algorithm, which calculates the least-cost path between two nodes in a network (Das *et al.*, 2019).

One of the key capabilities of GIS is its ability to compute shortest or fastest paths using established routing algorithms. Among these, Dijkstra's algorithm is widely regarded for its efficiency in calculating the shortest path from a source node to multiple destinations within a weighted network. The weights often represent distance, travel time, or any other impedance factor relevant to the problem at hand (Das *et al.*, 2019). By modeling road networks as graphs where intersections are nodes and roads are edges, Dijkstra's algorithm traverses the network to identify the least-cost path between points. This feature has made it a valuable tool for route optimization in sectors ranging from logistics and transportation to public safety and emergency healthcare.

Previous studies have highlighted the value of GIS in improving healthcare accessibility in both developed and developing regions as well as improving emergency service delivery. For instance, Makariye (2017) and Sari *et al.* (2021) demonstrated that Dijkstra's algorithm is effective in resolving shortest path problems in transport networks. Similarly, Mirino (2017) applied a combination of Dijkstra and Floyd-Warshall algorithms for ambulance dispatch optimization in urban Nigeria. Despite these advancements, there remains a paucity of practical GIS applications targeted at emergency routing in tertiary hospitals within Nigeria. This underlines the need for studies like this one that integrate local road networks, real-time spatial analysis, and hospital catchment areas to optimize emergency access routes.

Furthermore, hospital accessibility is not determined solely by road quality or route length. Factors such as population density, the spatial distribution of residential areas, and the concentration of healthcare demand also influence the effectiveness of emergency response systems (Guagliardo, 2004; Navaz *et al*. 2021). In high-density urban environments such as Egor Local Government Area, where UBTH is situated, these factors exacerbate the risks posed by delayed emergency interventions. This makes a geospatial approach that integrates road infrastructure with demographic data even more essential.

The growing interest in spatially-enabled emergency response systems reflects a broader trend toward the use of smart technologies in urban management (Allam and Newman, 2018). Across the globe, cities are implementing intelligent transport systems (ITS) and smart health infrastructure to meet rising demands for efficiency and responsiveness (Zanella *et al*., 2014; Akanbi *et al*., 2012). In Nigeria, however, such technologies are yet to be fully integrated into mainstream health logistics. Bridging this gap presents an opportunity for research-led innovation that can transform public health outcomes. This study is a step in that direction.

The present research employs GIS and Dijkstra's algorithm to develop a geospatial model for optimizing emergency response routes to the University of Benin Teaching Hospital. The study is centered on a 6.5-kilometer catchment area around UBTH, encompassing key neighborhoods from which patients are typically transported during emergencies. The analysis leverages spatial data on road networks, traffic behavior (assumed via average speed), and population clusters to calculate optimal paths and generate directional guides. By identifying the shortest and most efficient routes from various locations, including New Benin Market, Egor Market, Evbuotubu, Ziko Gas Station, and the National Museum, the model aims to minimize travel times and enhance emergency healthcare delivery.

The significance of this research lies in its potential to inform both policy and practice. By providing empirical evidence on route efficiencies and accessibility gaps, the study offers a decision-support tool for health authorities, ambulance operators, and urban planners. It also contributes to the broader discourse on health equity by addressing geographic disparities in access to emergency services, a known social determinant of health (Braveman et al., 2010). Moreover, the methodological framework employed here is replicable and can be adapted to other urban centers facing similar challenges in emergency health logistics.

The objectives of the study are threefold: (i) to establish the most efficient route to UBTH from selected points within the catchment area; (ii) to calculate travel times and distances based on network analysis; and (iii) to create visual and textual directional guides that support emergency navigation. The overarching aim is to demonstrate how geospatial intelligence can be applied to improve critical healthcare delivery in Nigeria's urban settings.

MATERIALS AND METHODS

Study Area

The study area covers the University of Benin Teaching Hospital (UBTH) is a multi-specialty healthcare service provider located in Egor Local Government, Benin city, Edo State, Nigeria (Zone 31N, UTM system) within the following given coordinates (788932.97 m E, 707068.95 m N; 790302.96 m E, 706377.78 m N), established on May 12, 1973 following the enactment of an edict of the Nigeria National Health Act (Wikipedia). Also having a bed capacity of approximately 850 bed spaces and is still increasing as new facilities are been added to the hospital (Obaseki et al., 2021). The University of Benin Teaching Hospital (UBTH) has up to 20 units some of which including: Accident & Emergency, Radiotherapy & Clinical Oncology, Orthopaedics & Traumatology, Pharmacy, Family Medicine, Child Health, Surgery, Radiology, Pathology, Family Medicine, Oncology, Obstretic gynaecology, Nursing and Midwifery, Internal Medicine, Physiotherapy and more. Figure 1 shows the map of the study area.

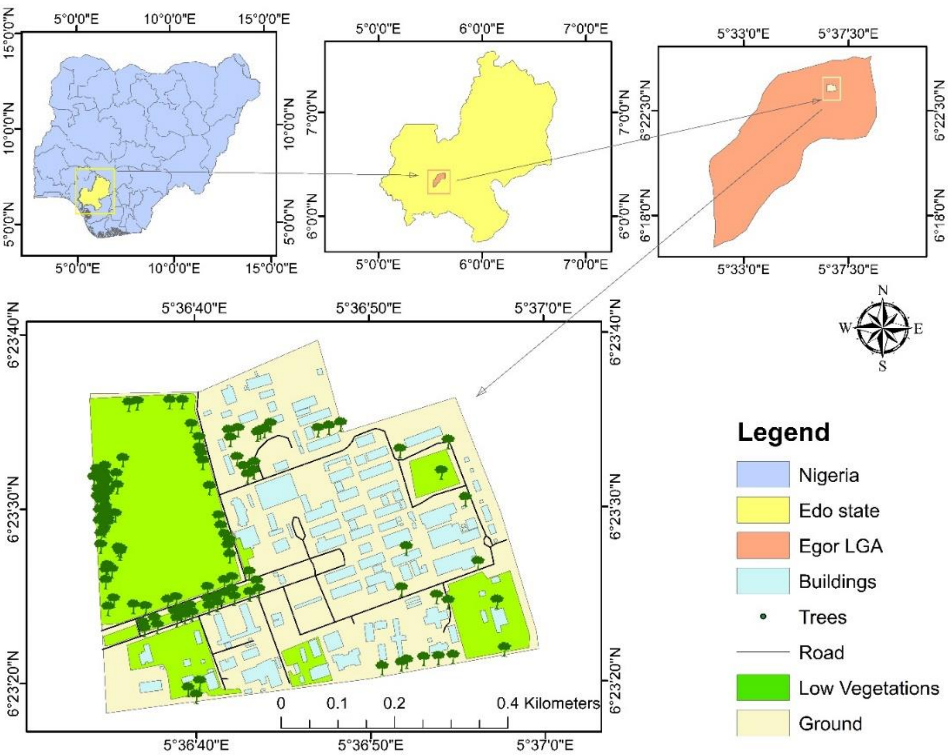

Figure 1: Map of the study area

Delineation of Catchment Area
The catchment area, a 6.5km radius, captured with a circular buffer having the University of Benin Teaching Hospital at its centre and the shapefile of Nigeria, Edo State, Benin city and Egor Local Government showing district boundaries are obtained from a free open-source site (OpenStreetMap). Andersen and Landex, (2008), described in detail how catchment can be delineated. The catchment area of the study is as shown in Figure 2.

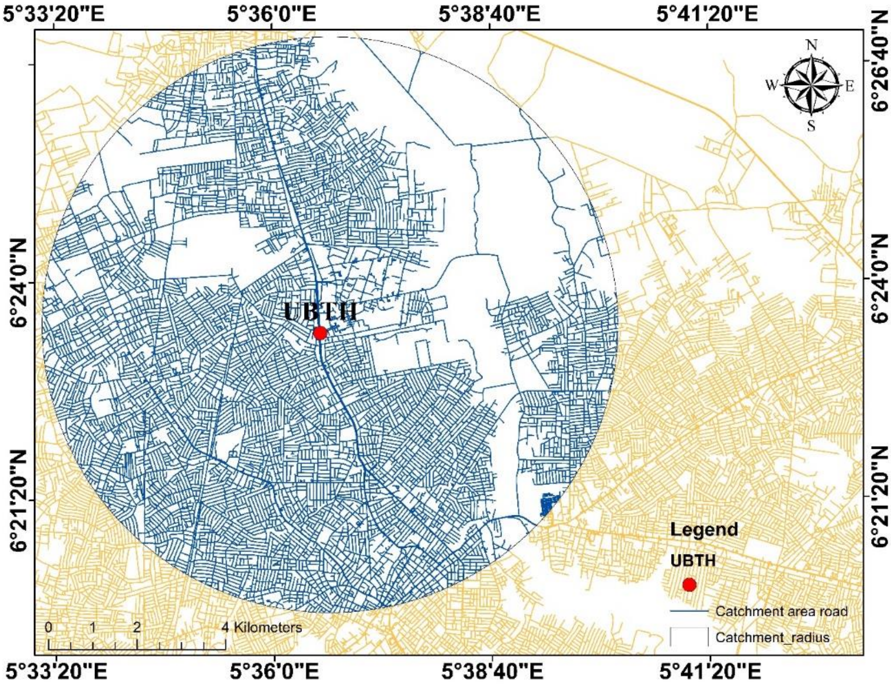

Figure 2: Delineation of the catchment area of study

Explanation on Dijkstra's Algorithm
Edsger Dijkstra published his algorithm of shortest paths discovery in 1959. The Dijkstra's Algorithm or model rely on graphs theory which can be adopted in modeling connections between objects, people, or entities. They components consists of two main elements: nodes and edges. The nodes represent objects while the edges represent the connections between these objects. The algorithm finds the shortest path between a given node referred to as the "source node" and all other participating nodes in a graph. The algorithm achieves this by using the weights of the edges to find the path that minimizes the total distance (weight) between the source node and all other participating nodes. A modification from Keller and Trotter (2024) for the Dijkstra's algorithm, it can be represented in a similar way to that of the principle of graphs theory. By assigning weights to the directed edges of a digraph it becomes very helpful to consider a pair (K, w), where: K = (S, M) is a digraph and w: M→N_o is a function assigning to each directed edge (x, y) a non-negative weight w (x, y). The weight is interpreted as the distance such that w (x, y) is taken as the length of the edge (x, y). Supposing $Z = (r = u_0, u_1, u_2, \ldots . u_t = x)$ is a directed path from r to x , then the length of the path Z is equal to the sum of the lengths of the edges within the enclosed path such that, $\sum_{i=0}^{t-1} w(u_i u_{i+1})$. The distance between point r to point x is then defined to be the minimum length of a directed path from point r to point x. This route network analysis has many applications in real life situations. Example of how the algorithm works is presented in Figure 3.

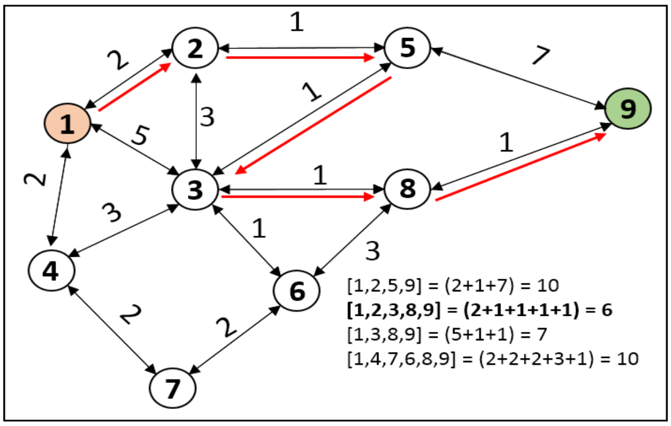

Figure 3: Dijkstra algorithm pathway
(Source: https://pages.cs.wisc.edu/~erics/)

Description of GIS Data Types
Table 1, shows the data type used in this research, the descriptions and examples. These data are collected from different secondary sources while some are primary such as the acquisition of location coordinates.

Table 1: Data types and Descriptions

S/N	Feature Type	Abbreviation	Description	Example
1	Point	Pt.	Refers to a location on the map	UBTH
2	Line	Li.	Refers to vector connection between point A to B.	Road
3	Polygon	Poly.	Refers to an enclosed shape on the map	Agor LGA
4	Table	Tab.	Refers to generic datatype in row and column	Census Data
5	Circle	Cir.	Refers to a buffer boundary	Buffer boundary

Data Acquisition Processes
The reliability and effectiveness of geospatial modeling for emergency response routing are largely dependent on the quality, resolution, and appropriateness of the spatial and attribute data used. In this study, data acquisition was carried out with careful consideration of the project's objectives: identifying optimal travel routes, computing travel times, and mapping service areas within a 6.5 km radius of the University of Benin Teaching Hospital (UBTH).

Spatial Data Collection
The primary spatial data used included: Road network data, Health facility location (UBTH), and Administrative and landmark points of interest (markets, museum, gas station, etc.). The road network data was obtained from OpenStreetMap (OSM) through ArcGIS-compatible shapefiles (Longley et al., 2015). This dataset contained geometry for various road classes, arterial, collector, and local streets, along with attribute fields such as road names, directionality, and travel impedances (Haklay and Weber, 2008; Neis et al., 2012; Longley et al., 2015). Each road segment was georeferenced within the Universal Transverse Mercator (UTM) coordinate system, Zone 31N, using WGS 1984 as the datum.
The UBTH location was digitized using high-resolution satellite imagery accessed via Google Earth Pro, with its central coordinates identified at approximately 788932.97 mE and 707068.95 mN. Similarly, origin locations (New Benin Market, Egor Market, Evbuotubu, Ziko Gas Station, and National Museum) were captured based on visible landmarks from satellite imagery and validated using local knowledge.

Attribute Data Collection
To support route optimization and travel time estimation, additional attribute fields were computed within the GIS environment. These included: Length of each road segment, measured in meters using GIS tools. Estimated travel time, computed by applying a uniform speed assumption of 40 km/h (converted to minutes). Turn-by-turn navigational logic, generated during network analysis to simulate real-life driving behavior. The road segments were enriched with these attributes to enable the application of Dijkstra's algorithm, which relies on distance and/or time weights to compute the least-cost path between nodes.

Administrative and Demographic Data
The study area boundary was defined using a 6.5 km buffer zone generated around UBTH. This buffer was created in ArcMap using the 'Buffer' tool to restrict the analysis to locations realistically within the reach of emergency response under 15 minutes. Administrative base layers, including Egor Local Government Area boundaries, were sourced from the National Space Research and Development Agency (NASRDA) archive and simplified for integration into the project's geodatabase.
Population data for Egor LGA were referenced from the 2006 Nigerian National Population Census and extrapolated to current values using a 2.5% annual growth rate. These estimates were used contextually to support catchment analysis and did not directly factor into routing but informed the interpretation of service coverage.

Software and Tools Used
All spatial data were processed and analyzed using: ArcGIS 10.8: for network dataset creation, shortest path analysis, service area modeling, and cartographic outputs. Google Earth Pro: for landmark validation and supplementary georeferencing. Microsoft Excel: for tabular computations, data entry, and summary statistics. Lenovo ThinkPad (4 GB RAM): as the primary workstation for data processing. The road network was converted into a network dataset using ArcCatalog, enabling the simulation of real-world travel scenarios through connectivity rules and directional cost analysis.

Optimized Shortest Route Map Creation
This is a map that shows the best possible travel route to the hospital cutting down distance and time. The shapefile (road shapefile containing characteristics such as street name) is imported through the directories into ArcGIS through the add data and ensure the data is properly projected to its coordinate system. Figure 4 shows the interface of the software during the preliminary data input and manipulation.

i. The shapefile (road shapefile containing characteristics such as street name) is imported through the directories into ArcGIS through the add data and ensure the data is properly projected to its coordinate system.
ii. Import point location of areas of interest.
iii. Add fields for Speed, Length and Minutes.
iv. Create a file geodatabase for storing data.
v. Go to the catalog and through the directory create a network dataset from the road data and turn on the direction.
vi. Add the Network analysis extension and click on the add Route drop down.
vii. A new ribbon of tools is added, right click on the 'stop' button, click 'load locations' and add two-point location, one which is the starting point and the other, the destination (UBTH).
viii. Click on the tool icon right of the new ribbon drop down and click on the 'Analysis settings' and set the impedance on Length.
ix. Click on the solve tool to create the shortest route between the two points.
x. Do same for the remaining points.

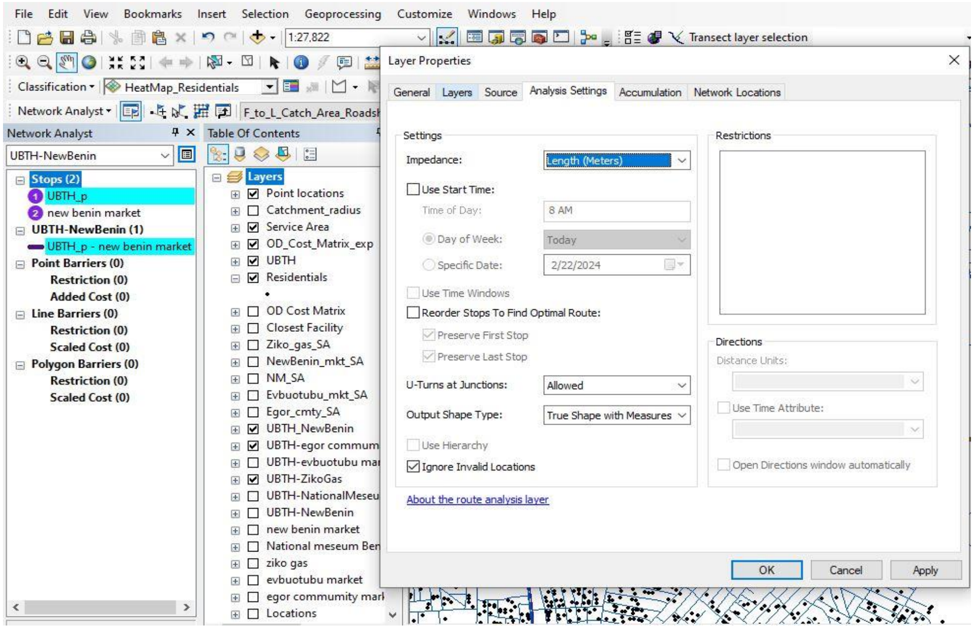

Figure 4: Data preparation in ArcGIS 10.8

Creation of Service Area Map

This is used in figuring out the closest points of interest (that is, the hospital), from several starting points or along a route. It can assist in maximizing routes for delivery trucks, emergency services, and even regular commuting. The tool takes into account the characteristics of the network dataset, such as traffic patterns and speed limits on the roads, and determines the shortest or least expensive path based on predetermined parameters, like cost, travel time, or distance. Steps involved in the creation of the service area map are as follows:

i. From the created network dataset, click on the network analysis tool and select the service area button.
ii. A new ribbon is created, right click on the facilities button and click load locations.
iii. Select the service area properties and navigate to the analysis settings.
iv. Set the impedance on Length as the cost.
v. Also set the 'default breaks' at 400, 600, and 1000 in meters, and then click OK.
vi. Click on the solve tool. This creates a polygon buffer of the chosen radius.
vii. Figure 5 shows the map of service area produced using the procedures highlighted above.

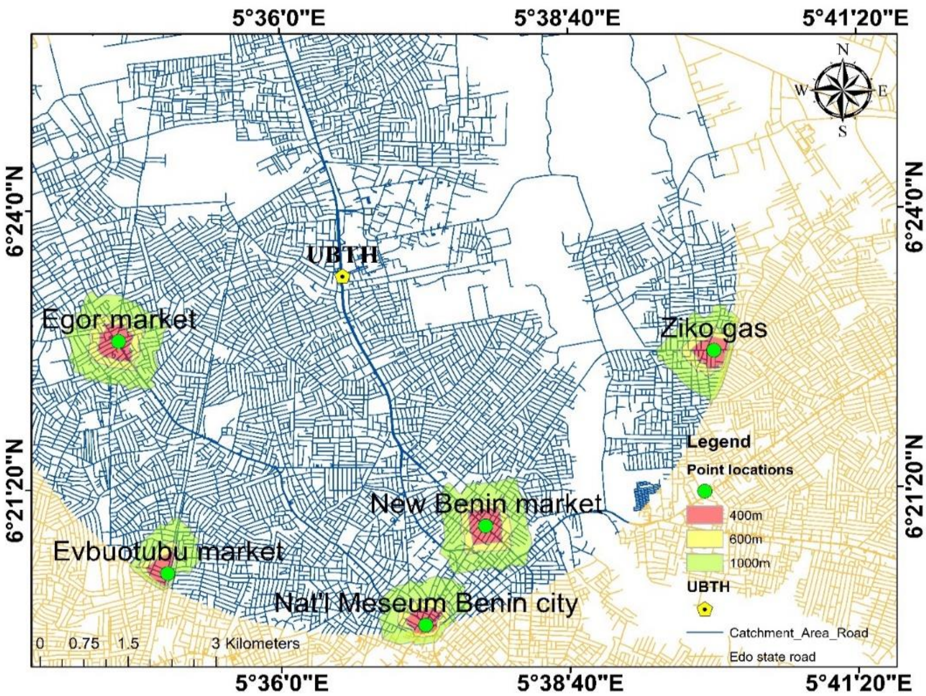

Figure 5: Service area maps of the locations of interest

Creation of Closest Facility Map

The closest facility tool is part of the Network Analysis extension, which allows the user to perform route network-based analysis. This tool is used to find closest facilities (such as hospitals, fire stations and others) to a set of incidents (such as emergencies, patients) based on network dataset representing the route network.

i. From the already imported shapefiles and created Network dataset, create a closest facility map from the network analysis drop down menu.
ii. Right click on facilities and load the locations, right click the incidents and load the incidents as residentials which has been converted to points using the feature to points tool).
iii. Select the length cost as the impedance in the analysis settings.
iv. Click the solve button on the network analysis tool bar to generate and visualize the result and accept if the result of the analysis is adequate.

Procedure for Creating Origin-To-Destination Cost Matrix Map

The origin-to-destination cost matrix tool in the network analysis tool box is used to calculate the travel distance (travel time) between multiple pairs of origins and destination on a road network. The steps involved in the creation of the OD cost matrix map;

i. Using the already created Network dataset and click on the network analysis tool bar and select from the dropdown OD cost matrix.
ii. Right click on the origin and load locations chosen to be the origin and also right click on Destination and load the relevant points
iii. On the right side of the network analysis tool, click and navigate to analysis setting select the Length cost as the impedance
iv. Click the solve button on the network analysis tool bar to generate and visualize the result.

Figure 6 shows the area that can be access from the different locations within a 2km area. The points on the map represents the residentials buildings and facilities, and the lines connects each resident within the 2km area to the destined points.

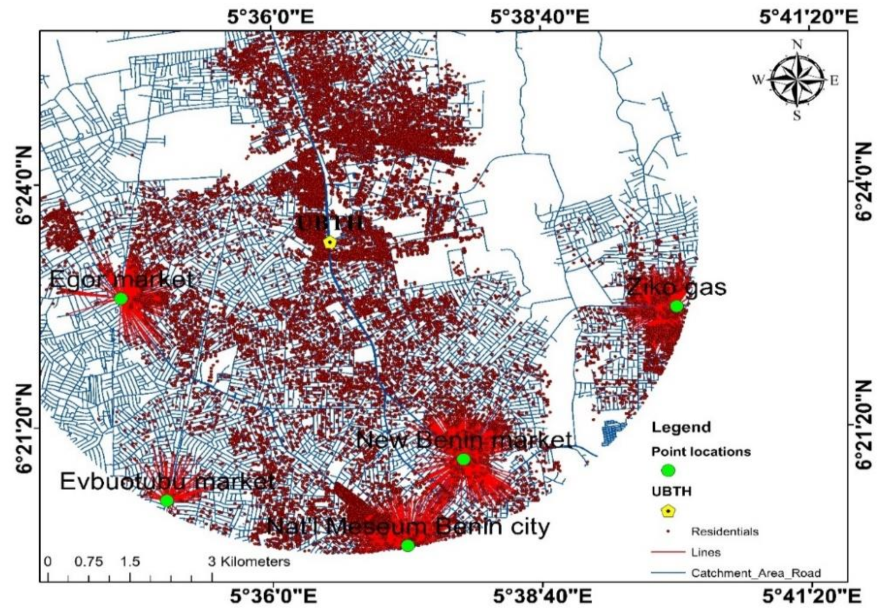

Figure 6: Original-Distance(OD) cost matrix map

RESULTS AND DISCUSSION

The findings of this study are presented in alignment with the study's objectives, with a unified discussion of results to highlight both the spatial patterns observed and their implications for emergency medical logistics. Through the integration of GIS and Dijkstra's algorithm, the analysis focused on optimizing access routes to the UBTH from surrounding urban neighborhoods within a 6.5-kilometer catchment area. The results provide actionable insight into route efficiencies, travel time estimates, and spatial accessibility challenges as shown in the following sub-sections.

Determination of Travel Time and Distance from Designated Locations to UBTH

To address the first objective, identifying the most efficient route to UBTH from various locations within the hospital's catchment, five locations were selected based on their strategic importance and proximity: New Benin Market, Egor Community Market, Evbuotubu Market, Ziko Gas Station, and the National Museum. The Dijkstra algorithm was implemented through ArcGIS 10.8, utilizing road network vector data with assigned cost attributes (distance and estimated travel time) to determine the shortest possible routes. The shortest and most efficient route to UBTH was found to be from New Benin Market, with a calculated travel distance of 5,251.5 meters and an estimated travel time of 8 minutes, assuming a constant average speed of 40 km/h. This route featured minimal directional complexity and passed through well-connected road segments, making it ideal for emergency vehicular movement. Closely following this was the Egor Community Market route, which covered 5,449.4 meters in the same estimated time. In contrast, the longest route was from Ziko Gas Station, which spanned 8,541.1 meters and required approximately 13 minutes of travel. Routes from the National Museum and Evbuotubu Market fell in between, with respective travel times of 10 and 12 minutes. Figure 7 shows the shortest distance map while Table 2 shows the summary of the route analysis results.

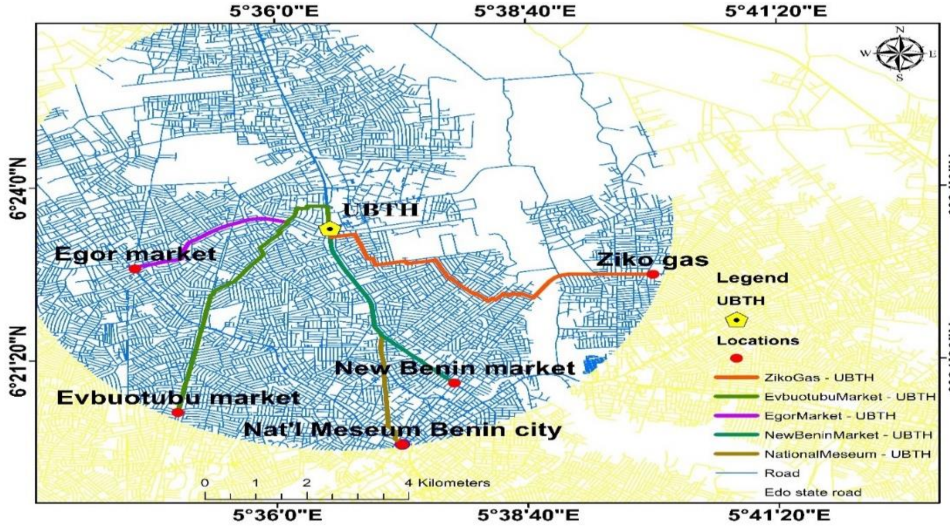

Figure 7: Shortest route map from different locations to UBTH

Table 2: Route Analysis Results

Location	Distance (m)	Estimated Time (min)
New Benin Market	5,251.5	8
Egor Community Market	5,449.4	8
National Museum	6,594.1	10
Evbuotubu Market	8,031.8	12
Ziko Gas	8,541.1	13

These findings reflect the critical importance of location-specific route planning in emergency healthcare provision. The variation in travel time, despite relatively short distances, underscores how urban layout and road complexity affect emergency response outcomes. While all locations fall within the defined catchment buffer, spatial impedance varies due to road connectivity and network structure.

Calculation of Location Parameters

The second objective is to calculate the travel time and distance from each location. This was addressed through a combination of route solving and direction-based analysis. Each route was dissected into its individual segments, where distance and estimated time were calculated for each leg. For example, the route from Evbuotubu Market required navigating 19 unique segments, including several turns through minor and connector roads, leading to a total distance of 8.03 km and a travel time of 12 minutes. In contrast, the route from New Benin Market involved fewer turns and longer, more continuous road segments, contributing to its shorter travel time. This highlights a key insight that, route efficiency is not solely a function of total distance but also of road continuity and complexity. While Dijkstra's algorithm optimized for distance, the routes with more straightforward navigation also inherently reduced the chance of driver error or delay in emergency situations. In line with findings from Hao *et al*. (2024), this affirms that spatial simplicity such as fewer intersections and clearer paths enhances the effectiveness of emergency transport. Table 3 presents the result of the directional guide.

Table 3: Represents the Directional Guide From New-Benin Market to UBTH

ROUTE: NEW BENIN MARKET - UBTH		Length(m)	Time (min)
1.	Start at New Benin Market	0	0
2.	Go southwest on Mission Road toward New Lagos Road	5.0	<1
3.	Turn right on New Lagos Road	1848.9	3
4.	Turn right and immediately turn left	3390.9	5
5.	Turn right	6.6	<1
6.	Finish at UBTH, on the right		
	Total Length and Time	**5251.5**	**8**

This route is the shortest and most efficient, covering a total distance of 5,251.5 meters in an estimated 8 minutes. It features only five navigational steps, primarily along Mission Road and New Lagos Road, two well-established arterial roads. The low number of turns and high road continuity reduces travel complexity, making this the most reliable option for emergency response. The spatial simplicity of this route makes it ideal for deploying ambulances with minimal risk of navigation error or delay. Table 4 presents the result of the directional guide to UBTH from Egor.

Table 4: Represents the Directional Guide from Egor Community Market to UBTH

EGOR COMMUNITY MARKET - UBTH		Length(m)	Minutes (min)
1.	Start at Egor community market	0	0
2.	Go northwest on Upper Siluko Road	65.4	<1
3.	Make sharp right	712.9	1
4.	Continue on Uwelu Road	294.1	<1
5.	Turn left	2583.8	4
6.	Turn left	469.6	<1
7.	Turn right	218.6	<1
8.	Turn left	69.1	<1
9.	Turn right	395.9	<1
10.	Turn right	626.0	<1
11.	Turn left	14.1	<1
12.	Finish at UBTH on the right		
	Total Length and time	**5449.4**	**8**

Although slightly longer at 5,449.4 meters, this route maintains a similar travel time of 8 minutes. It is, however, more complex, involving 11 directional steps that include multiple turns along Uwelu Road and several short connectors. While the travel distance remains within optimal limits, the number of transitions introduces a higher risk of delay during periods of congestion or inclement weather. Nonetheless, it remains a viable and efficient secondary route for emergency operations. Table 5 presents the result of the directional guide.

Table 5: Represents the Directional Guide From Evbuotubu Market to UBTH

EVBUOTUBU MARKET - UBTH		Length (m)	Minutes (min)
1.	Start at Evbuotubu market	0	0
2.	Go north	441.5	<1
3.	Continue on 1st Power Line	1398.1	2
4.	Continue	665.1	<1
5.	Continue on Ojo street by Powerline	891.3	1
6.	Turn right	51.2	<1
7.	Turn left	441.8	<1
8.	Turn left and immediately turn right	1137.2	2
9.	Turn left	200.0	<1
10.	Turn right	588.7	<1
11.	Turn left	75.3	<1
12.	Turn right	297.2	<1
13.	Turn left and immediately turn right	520.6	<1
14.	Turn right	218.6	<1
15.	Turn left	69.1	<1
16.	Turn right	395.9	<1
17.	Turn right	626.0	<1
18.	Turn left	14.1	<1
19.	Finish at UBTH, on the right		
	Total Length and Time	**8031.8**	**12**

This route spans a significantly longer distance of 8,031.8 meters, with a corresponding travel time of 12 minutes. It is also the most navigationally demanding, requiring 19 steps, many of which occur along minor roads like Ojo Street and Powerline. The high number of turns and the dependence on residential streets increase the likelihood of response delays, especially under pressure. This route underscores the need for local navigation aids or possibly a mobile ambulance substation closer to the area. Table 6 presents the result of the directional guide to UBTH from Ziko Gas.

Table 6: Represents the Directional Guide From Ziko Gas to UBTH

ZIKO GAS TO UBTH		Length(m)	Minutes(min)
Start at Ziko gas		0	0
1.	Go west	2344.0	4
2.	Continue on Mission Road	321.1	<1
3.	Turn right	278.1	<1
4.	Turn left	64.8	<1
5.	Turn right	229.0	<1
6.	Turn right	127.1	<1

7.	Turn left on Eweka Street	241.1	<1
8.	Turn right	78.5	<1
9.	Turn left on Omofonmwan Street	120.4	<1
10.	Turn right on Asemota Street	330.9	<1
11.	Turn left on Okhoro Street and immediately turn right on Universal Road	722.3	<1
12.	Turn left on Oghobahase Street	39.1	<1
13.	Make sharp right on Aigbokhian Street	590.4	<1
14.	Turn left	576.9	<1
15.	Turn right	71.9	<1
16.	Turn left on Technical Road	616.1	<1
17.	Turn right	200.5	<1
18.	Turn left	98.3	<1
19.	Turn right	740.1	<1
20.	Turn left	489.7	<1
21.	Turn right	253.4	<1
22.	Turn right	6.6	<1
23.	Finish at UBTH, on the right		
	Total Length and Time	**8541.1**	**13**

At 8,541.1 meters, this is the longest and most complex route, requiring an estimated 13 minutes of travel and involving 22 navigation steps. The route winds through several residential and local roads such as Asemota Street, Okhoro Street, and Technical Road before arriving at the hospital. Its length and directional complexity significantly reduce its suitability for urgent medical transport. Emergency response strategies should consider alternative origin points or prioritize infrastructure upgrades in this corridor. Table 7 presents the result of the directional guide.

Table 7: Represents the Directional Guide From National Museum to UBTH

NATIONAL MUSEUM TO UBTH		Length (m)	Minutes (min)
1.	Start at National Museum Benin city	0	0
2.	Go east towards Oba Market Road	37.5	<1
3.	Make sharp left on Oba Market Road	233.4	<1
4.	Turn right on 1st Ibewe Street	311.3	<1
5.	Continue on Isekhere Street	148.4	<1
6.	Turn on Wire Road	1773.5	3
7.	Bear right	32.2	<1
8.	Bear right	1652.9	2
9.	Turn right and immediately turn left	2398.5	4
10.	Turn right	6.6	<1
11.	Finish at UBTH, on the right		
	Total Length and Time	**6594.1**	**10**

This route presents a moderate balance, with a total distance of 6,594.1 meters and an estimated travel time of 10 minutes. Comprising 11 navigational steps, it utilizes relatively direct roads such as Oba Market Road and Wire Road, which offer consistent traffic flow. The route is straightforward enough for emergency drivers and represents a solid secondary option when other shorter routes are unavailable.

Creation of Directional Guides to the UBTH

Further, the analysis of spatial service areas and the generation of an Origin-Destination (OD) cost matrix provided additional insight into accessibility within the hospital's catchment. The service area map showed the extents reachable from UBTH within buffer zones of 400m, 600m, and 1000m. While much of the core urban zone falls within these limits, outlying districts, particularly toward Evbuotubu and Ziko Gas, demonstrated weaker proximity connectivity. This spatial inequity suggests that travel time alone is insufficient for evaluating access; policymakers must also consider the distribution of population clusters and road infrastructure gaps. The OD matrix connected dozens of residential points to their nearest major road access nodes and then to UBTH, revealing that locations over 2 kilometers from arterial roads were consistently linked to longer travel times. This supports prior research by Guagliardo (2004) and Wang *et al.* (2018), who emphasized the role of road hierarchy and proximity in healthcare access modeling. Table 4 shows the length and time of each turns, also averaging at a speed of 40km/hr.

In line with the third objective, directional guides were created for each of the five routes. These included detailed step-by-step instructions listing turns, road transitions, and segment lengths. The guide from New Benin Market, for example, involved only five directional shifts, indicating ease of use and suitability for high-speed emergency navigation. On the other hand, the guide from Ziko Gas involved over 20 instructions, presenting not only a longer route but also a more mentally demanding navigation scenario for emergency responders. These route maps and directional guides serve as both practical tools for emergency responders and as visualizations for decision-makers. For example, the New Benin Market route could be prioritized for future ambulance outposts, while Ziko Gas could benefit from improved road connectivity or mobile response units.

The integrated results confirm that GIS-based analysis, when combined with intelligent routing algorithms like Dijkstra's, can dramatically enhance the planning and execution of emergency healthcare services. Not only can this approach reduce response times and streamline logistics, but it also identifies spatial disparities that might otherwise go unnoticed. Despite the significant level of success made in this study, its limitations must also be acknowledged. The analysis assumed constant travel speed and did not account for real-time traffic, road obstructions, or weather conditions. While this allowed for a controlled analysis, future studies should integrate dynamic datasets using real-time GPS and IoT-based traffic feeds to enrich route accuracy.

Nonetheless, the study's implications are far-reaching. The geospatial model developed here offers a replicable framework for other tertiary hospitals across Nigeria and sub-Saharan Africa. As cities grow and health demands intensify, integrating GIS into emergency planning will no longer be optional, it will be essential.

CONCLUSION

The integration of GIS with Dijkstra's algorithm offers a robust solution for optimizing emergency response routes to critical healthcare facilities such as the UBTH. This study established efficient travel routes from key locations within a 6.5 km radius, reducing average travel time and improving accessibility. The results provide actionable intelligence for health planners, policymakers, and emergency responders, offering a foundation for strategic health resource allocation. While the study was limited by the absence of live traffic and weather data, its methodology remains replicable and adaptable to other urban centers facing similar accessibility challenges. The deployment of GPS-enhanced emergency navigation systems is recommended to further operationalize the insights gained. Ultimately, geospatial solutions such as this will be central to improving health outcomes and building resilient healthcare systems in Nigeria and beyond.

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