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Optimization of Bus Routes Network in Federal Capital City Abuja, Nigeria

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ORIGINAL RESEARCH

Abstract— The lack of optimal bus routes has been a great problem for the effective operation of the transport system in the Federal Capital City. This has resulted to challenges, such as, inadequate accessibility to public buses, long time of walking to or waiting at bus stops as faced daily by commuters.The results of the assessment of the current bus route network in the Federal Capital city suggested that there is need to optimize the present bus route networks to connect with all the districts of the City for overall accessibility to commuters. This study therefore determines the optimum bus route network for the City using Ant Colony Optimization Technique. Geographic Information Systems (GIS) were utilized to determine more efficient passenger routes based on the insights derived from the trip distribution analysis. Consider factors such as travel time, travel distance, traffic congestion, and transportation mode preferences to develop passenger routes that are both time-efficient and cost-effective. A combination of an interview, a questionnaire and a GPS (Garmin76x) was used to gather information from commuters and public transportation operators to determine trip production and attraction of districts; travel time and travel distance from districts to districts. Geographic Information System (GIS) in Arc-GIS 10.6.1 environment, was employed to analyze and modify the gathered data to digitize the map of the City showing districts, road network and trip distribution of residents. The study revealed that the current bus routes network does not cover the routes that have concentration points of movement of commuters; therefore, compared to public buses, which have fares ranging from ₦50 to ₦100 every drop, passengers who use registered taxis and unofficial private automobile taxis spend excessive amounts of money on transportation fees. These taxis' fares range from ₦200 (400%) to ₦500 (500%) per drop. The optimized and optimum bus routes network provided in this study are suggested for implementation to facilitate an effective bus service operating system in the Federal Capital City.

Keywords— Bus routes, Ant colony, optimization, Passengers and GPS (Garmin76x)

1. INTRODUCTION

Both scientific and industrial phenomena present a wide range of optimization challenges. Timetable scheduling, nurse time distribution scheduling, railway scheduling, capacity planning, and issues with traveling sales people are a few of them. Various methods are now being utilized to resolve challenging discrete optimization problems, and they are all inspired by the foraging activity of ant colonies. Actually, the most popular and effective algorithm based on behavior is the Ant Colony Optimization (ACO) technique (Sapna *et al.*, 2015). Ants have been the inspiration behind several methodologies and strategies, the most well-researched and effective of which is the general-purpose optimization methodology called ant colony optimization (Marco *et al.*, 2006). Since the initial ant colony optimization algorithm was introduced in the early 1990s, more researchers have become interested in ACO, and there is now a plethora of effective applications accessible (Marco *et al.*, 2006)). The behavior of actual ant colonies served as the model for the meta heuristic technique known as Ant Colony Optimization (ACO) Masoumeh and Ahmad (2009) . By carrying out a series of easy operations that either maximize or minimize a certain criterion, construction heuristics produce workable solutions. The well-known savings heuristic developed by Clarke and Wright (1964) is one of these techniques that continues by combining two routes into one, based on the savings from the merger. Other notable examples of construction heuristic are the sweep algorithm by Gillett and Miller (1974) , the Christofides *et al.*, (1979) insertion heuristic, the Renaud *et al.*, (1996) and the enhanced Paessens (1988) savings heuristic. Further information is provided by a parametric study of several construction heuristics in the survey publications of Laporte *et al.*, (2000), Laporte and Semet (2001), and Van Breedam (2002). Ants live in colonies; they walk about randomly from their nest in search of food or foraging locations. As they move around, they deposit a substance known as pheromone on the ground along their path, which other ants smell to trail the identified route. The frequency of their movement along a route is shown by the concentrations of the pheromone deposited on the route. When there is an obstacle along the way, they try to move around it, using different routes until they establish the best or shortest path to their food location. Ants are self-organized and have no central control; their decision is based on critical assessment of frequency, favourable and unfavourable information as they move randomly between their nest and food location.Tour-improvement heuristics, on the whole, yield higher-quality results than tour-constructive heuristics, as demonstrated by experiments Reinelt (1994).

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Section E- CIVIL ENGINEERING & RELATED SCIENCES
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2.0 BACKGROUND OF STUDY

Several scientists, including Shimamoto (2010) and Gao (2004), have each developed models for calculating the best prices to charge or the best transit frequency to use. Yang (2007) suggested a strategy for optimizing the bus network, whose goal was to maximize the number of people traveling without transfers, then used a simultaneous ant colony approach to solve the model. Petrelli (2004) put forward a model for enhancing feeder bus lines, in which switching between feeder buses was prohibited and the railway's fixed point of transfer to a feeder bus. Shimamoto (2010) enlarged the model to improve both the frequencies and routes of public transit, and they used an actual network to test their model. Chen and Yang (2000) created a model that improved where the bus route should go, reducing the total operator and user costs will increase operational headway. In his analysis, Wang *et al.*, (2018) took into account the constraints imposed by the start and stop times of the bus routes that were personalized for passengers. Using the Cplex program, Li *et al.*, (2018) solved a mixed-load custom bus routing model that complies with the time window's specifications. To improve vehicle pathways and assign vehicles, Carol Tong *et al.*, (2017) developed an optimization model that suits the time window and passenger needs. A bus stop's position and route were suggested by Guo *et al.*, (2018) who also developed a mixed-integer programming model to explain the challenge of customized bus routing. According to Huang *et al.*, (2020) the operation of customized buses can be separated into dynamic and static stages. To optimize the design of customized bus routes, two-stage optimization models are utilized. To address real-time customized bus route optimization issues under random passenger demand, Wang *et al.*, 2020 presented a two-stage approach for model solving. The customized bus model, fixed operating cost, and weight of each subcost were all explored by Han *et al.*, (2019) who also introduced a customized bus network planning strategy to reconcile the interests of operators, society, and passengers. Ali (2014) looked at how good Federal Capital City Abuja's transportation system is; the results showed that passengers' expectations are not being met by the public bus service. Based on the evaluation of the effectiveness of the city's transportation services by Ojekunle (2016), it was deduced that government should improve on the existing services. Korve et al., (2019) developed an Urban Mass Transit Optimization Model by formulating a Two Shift System using Integer Linear Programming to optimize the Abuja Mass Transit System on seven routes to satellite towns, which does not cover the districts of the City. Public transport was examined in the study done by Pillah (2023) by considering four aspects, the costs of transport fare, service frequency, distance in approaching the transport points and time spent waiting at the terminals/bus stops. As for the onward bus route networks, the study suggested that the current bus route networks should be expanded to cover all the districts of the Federal Capital City in a bid to improve bus accessibility and the delivery of the service to the commuters. Olonisakin et al., (2023) assessment of the current bus route systems along the provision of public transport bus services in the FCC., recommended optimization of the present bus route networks for overall accessibility to commuters.

This work therefore, presents the optimum bus routes network in the Federal Capital City, through the following objectives:

i. Determination of trip distribution and bus routes detail within the Federal Capital City.
ii. Determination of additional bus routes network within the Federal Capital City; and
iii. Provision of optimum bus route network within the City

However, this paper is limited to the trip distribution and optimal bus route network within the Phase I of Federal Capital City, Abuja in Nigeria

3.0 METHODOLOGY

The methodology adopted here in for the work includes:

(i) Passenger's trip survey count to determine trip production (Pi)

Passengers trip survey count were carried out at three locations in each district of the phase 1, FCC; The total daily average count from the nine districts were added together to form the trip production (Pi)

(ii) Passengers Trip Attraction (Aj)

According to responses to the questionnaire's origin and destination (O - D) questions, the percentages of travelers choosing each district as their final destination were calculated to create the Trip Attraction (Aj) to districts.

(iii) Average times taken to travel from district to district

The average travel times from districts to districts in FCC, were calculated using answers to survey questions and information from GPS (Garmin76x) data of traffic conditions on intra-city routes in the City.

(iv) Trip Distribution: Gravity model expressed according to Garber, *et al.*, (2010)

$$T_{i-j} = P_i \left[\frac{A_{ij} F_{ij} K_{ij}}{\sum \left(A_{ij} F_{ij} K_{ij} \right)} \right]$$

was used for trip distribution considering the nine districts in the City, Abuja. The districts are: Garki I, Garki II, Wuse I, Wuse II, Wuse IIA, Wuse IIB, Central Business, Maitama I, Maitama II and Asokoro. Trip distribution matrix and tables were developed.

(v) Geographic Information Systems (GIS)

GIS was utilized to determined more efficient passenger routes based on the insights derived from the trip distribution analysis. Consider factors such as travel time, travel distance, traffic congestion, and transportation mode preferences to develop passenger routes that are both time-efficient and cost-effective. In GIS trip distribution refers to the process of estimating the flow of trips or movements between different origins and destinations within a geographic area. Trip distribution analysis involves understanding the patterns of travel behavior and the spatial interaction between various locations, which is essential for transportation planning and infrastructure management. GIS was used to digitize the map of the City showing road network, districts and trip distribution. The street guide and topographical maps of Abuja were scanned and loaded into ArcGIS 10.6.1 (ArcCatalog and ArcMap Version 10.6.1; (2018). After loading the images into ArcGIS*10. 6.1, they were registered to conform to Universal Transverse Mercator (UTM) Coordinate system with World Geodetic System (WGS) 1984 UTM ZONE 32North. Then, the images were geog-referenced, and exported to ArcView 10.6.1 software environment. It was from this environment that on-screen digitizing was carried out. Details on the images were traced out in segments as points, lines and polygons.

(vi) Optimum bus route

Ant-Colony-Observation is a constructive algorithm grounded on the foraging behaviour of ants and it has more benefits than other optimization algorithms for example; Adaptability, Parallelism, Robustness, Flexibility, Incorporation of Heuristics, Potential to Converge and Enhanced Performance. An ant colony technique for route optimization was implemented using Python software. This code implements the Ant Colony Optimization (ACO) algorithm with 2-opt local search and diversification to solve the Traveling Salesman Problem (TSP). The code starts by importing the necessary libraries, namely NumPy for mathematical operations and time for tracking the time taken by the algorithm. The main function of the code is the ant_colony_optimization_2opt_diversified function. This function takes as input the time matrix, pheromone matrix, number of ants, number of iterations, pheromone evaporation rate, and diversification rate. It initializes variables to keep track of the best tour found so far and its length, as well as all tours and their lengths. The function then proceeds to run the ACO algorithm for the specified number of iterations. In each iteration, it generates tours for each ant by selecting the next district based on probabilities that depend on the pheromone levels and time to the unvisited districts. The diversification rate is used to randomly select a district with uniform probability instead of using the probabilities calculated from the pheromone levels and time. The pheromone levels are updated based on the length of each tour and the pheromone evaporation rate. The pheromone levels are increased for each edge visited in a tour proportional to the inverse of the tour length. The function prints out the tours found so far including, the route, and the time taken to traverse the tour

3.1 Federal Capital City, Phase 1 Abuja as the Study Area

Figures 2, is map of FCT showing Abuja city centre. The phase 1 of federal capital city consists of Nine districts namely: Garki I, Garki II, Wuse I, Wuse IIA,Wuse IIB, Central Area, Maitama I, Maitama II and Asokoro as shown in figure 3

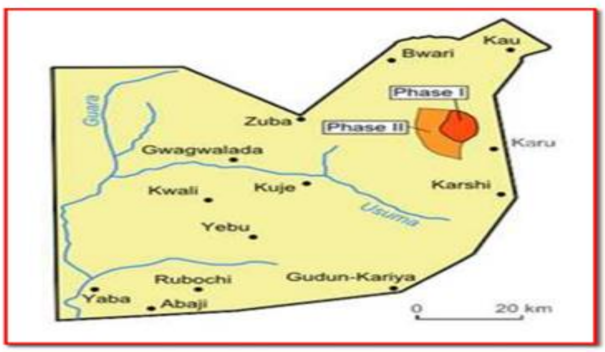

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Figure 2: Map of FCT Showing Abuja City Centre (Phase 1)

4.0

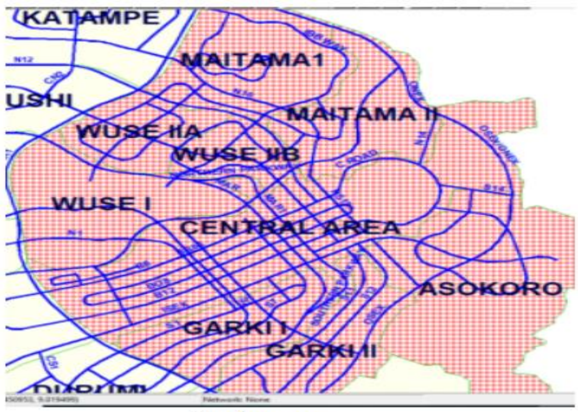

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Figure 3: Map of Phase 1 of FCC showing the nine districts

4.0 RESULTS AND DISCUSSION

4.1 DETERMINATION OF TRIP DISTRIBUTION AND BUS ROUTES DETAIL WITHIN THE FEDERAL CAPITAL CITY

a) Trip Production (P_i): The result of passenger's trip survey counts carried out at the nine districts is shown on Table 1

(b) Trip Attraction (A_j) **f**rom response to origin and destination (O – D) questions on the questionnaire administered, 18.53% indicates central business district as destination (this is due to the Federal Secretariat and other government offices available at this district). Trip Production (P_i) and Attraction **(A_j)** from districts to districts are shown on Table 2

Table 1: Trip production from 9 districts

S/N	Districts	Trip Production (Pi)
1	Garki	1,800
2	Garki ll	1,300
3	Wuse	2,000
4	Wuse ll A	1,000
5	Wuse ll B	900
6	Central Business	800
7	Maitama l	1,200
8	Maitama ll	1,100
9	Asokoro	1,070
	Total	11,170

Table 2: Trip Production (Pi) and Attraction (Ai) from district to district

Districts	Trip Production (Pi)	Trip Attraction (Ai)
Garki	1,800	1,150
Garki ll	1,300	1,000
Wuse	2,000	1,380
Wuse ll A	1,000	1,300
Wuse ll B	900	1,100
CBD	800	2,070
Maitama l	1,200	1,170
Maitama ll	1,100	1,200
Asokoro	1070	800
Total	11,170	11,170

c) Average times taken to journey from districts to districts

The average times taken to journey from districts to districts in **minutes** are shown on Table 3

(d) **Time - friction ratio**

Time - friction ratio explains that the less the travel time to a destination the more the attraction to the location, that is, the friction factors are higher as travel time decreases Garber, *et al.*, (2010). Thus time -friction ratio is shown on Table 4

Table 3: Average times taken to journey from district to district in minutes

	Garki	Garki ll	Wuse	Wuse llA	Wuse llB	CBD	Maitama l	Maitama ll	Asokoro
Garki	6	7	9	18	18	10	20	22	7
Garki ll	7	5	15	20	23	20	25	27	6
Wuse	9	15	6	8	9	7	10	10	20
Wuse llA	18	20	8	5	7	10	8	9	20
Wuse llB	18	23	9	7	5	8	5	6	20
CBD	10	20	7	10	8	5	6	5	15
Maitama l	20	25	10	8	5	6	5	7	16
Maitama ll	22	27	10	9	6	5	7	5	15
Asokoro	7	6	20	20	20	15	16	15	5

Table 4: Time - friction ratio

Time	1	2	3	4	5	6	7	8	9	14
Frequency	82	52	50	41	39	26	20	13	8	3

(e)Trip Distribution using Gravity Model

$$T_{i-j} = P_i \left[\frac{A_{ij} F_{ij} K_{ij}}{\sum (A_{ij} F_{ij} K_{ij})} \right]$$

Tables 5 shows calculated trip distributions from districts to districts, and table 6 presents Trip distribution and bus routes detail of FCC

4.2 DETERMINATION OF THE ADDITIONAL BUS ROUTES NETWORK WITHIN THE FEDERAL CAPITAL CITY

Trip distribution and bus routes detail on Table 6 were used to create attribute table's data in ArcGIS, which enabled the production and display of the trip distribution on the Map of Abuja city centre as shown in Figure 3. In ants colony optimization, the optimized routes are identified by the high concentration of pheromone, the substance that the ants deposit on the ground as they walk around in search of food. Likewise, the trip distribution in Figure 3 shows the optimized routes that have a concentration of movement of people as they carry out their daily activities withing the City.

Most of these routes are not covered by the current bus routes network, which makes accessibility to the bus services very poor. In view of this, the determined Bus Routes network and Bus Stops at a spacing of 400 metres from this study is shown in Figure 5 , while that of the existing one is in Figure 4

Tables 5: Calculated trip distributions from districts to districts

		TRIP DISTRIBUTION TO DISTRICTS										
		Garki	Garki II	Wuse	Wuse II A	Wuse II B	CBD	Maitama 1	Maitama II	Asokoro	Calculated Trip Production	Actual Trip Production
TRIP DISTRIBUTION FROM DISTRICTS	Garki	552	341	284	31	30	218	31	34	279	1800	1800
	Garki ll	334	522	28	24	23	34	24	27	284	1300	1300
	Wuse	115	11	624	270	161	591	104	115	9	2000	2000
	Wuse ll A	7	5	144	375	186	68	125	85	5	1000	1000
	Wuse ll B	5	4	62	133	251	123	260	59	3	900	900
	CBD	16	3	109	23	59	262	123	203	2	800	800
	Maitama l	5	4	44	100	290	284	300	169	4	1200	1200
	Maitama ll	5	4	40	55	174	384	138	297	3	1100	1100
	Asokoro	281	293	24	20	20	30	20	22	360	1070	1070
	Calculated Trip Attraction	1320	1187	1359	1031	1194	1994	1125	1011	949	11,170	11,170
	Actual Tip Attraction	1150	1000	1380	1300	1100	2070	1170	1200	1800	11,170	11,170

Table 6: Trip distribution and Bus Routes detail of Federal Capital City

S/N	Districts	Routes	Distance Travel (km)	Time taken (min)	Journey (km) Trip Production	Trip Attraction
1	Garki - Garki	Moshood Abiola Way	2.3	6	1,800	552
2	Garki - Garki ll	Ring Road l, Ahmadu Bello and Ladoke Akintola w	3.2	7	1,800	341
3	Garki - Wuse	Moshood Abiola and Olusegun Obasanjo way	2.9	9	1,800	284
4	Garki - Wuse llA	RRI, Sani Abasha and Kashim Ibrahim way	5.2	18	1,800	31
5	Garki - Wuse llB	RRI,Sani Abasha and Ibrahim Babangida way	5.3	18	1,800	30
6	Garki - CBD	Moshood Abiola and Herbert Macaulay wa	4.8	10	1,800	218
7	Garki-Maitama l	RRI, Herbert Macaulay and Kashim Ibrahim wa	5.8	20	1,800	31
8	Garki-Maitam ll	RR I, Herbert Macaulay and Kashim Ibrahim wa	6.0	22	1,800	34
9	Garki - Asokoro	Ringroad l	3.5	7	1,800	279

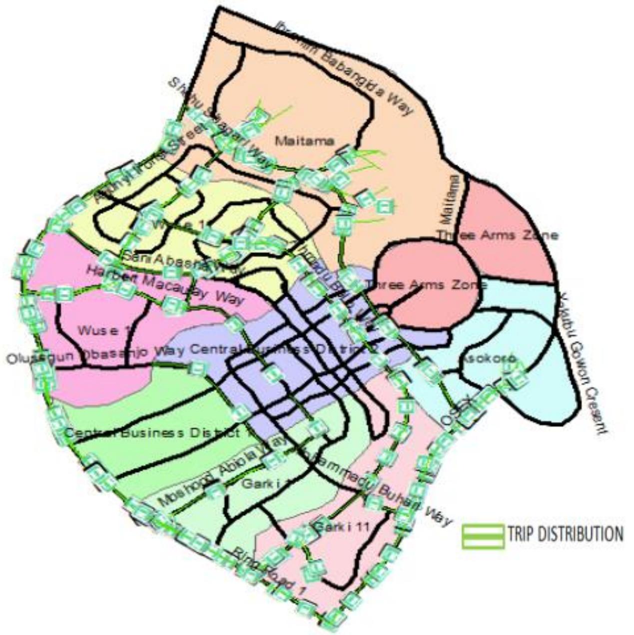

Figure 3: Show showing the Trip-distribution

Figure 4: Existing Bus Routes **Figure 5**: Optimized Bus Routes (Existing and Additional)

4.3 PROVISION OF OPTIMUM BUS ROUTE NETWORK WITHIN THE CITY

The work by Korve et al., (2019) who used Integer Linear Programming for the optimization of Urban Mass Transit in Fedearal Capital City does not focus on the districts of the City. Therefore Python code was used to implements the Ant Colony Optimization (ACO) algorithm with 2-opt local search and diversification to solve the Traveling Salesman Problem (TSP). The function prints out the tours found including, the route, and the time taken as shown in Figure

```
18    route [0 2 3 4 6 5 7 8 1], time taken 68.0 minutes
19    route [5 2 3 4 6 7 8 1 0], time taken 72.0 minutes
20    route [2 3 6 4 7 5 8 1 0], time taken 69.0 minutes
21    route [2 0 1 8 5 7 3 4 6], time taken 73.0 minutes
22    route [3 4 6 5 7 8 1 0 2], time taken 68.0 minutes
23    route [1 8 0 2 5 7 6 3 4], time taken 79.0 minutes
24    route [4 6 3 7 5 8 1 0 2], time taken 73.0 minutes
25    route [1 0 8 6 4 3 2 7 5], time taken 85.0 minutes
26    route [3 4 6 7 5 2 1 8 0], time taken 77.0 minutes
27    route [8 1 0 2 5 7 6 3 4], time taken 76.0 minutes
28    route [5 7 6 4 3 2 1 8 0], time taken 70.0 minutes
29    route [6 5 2 0 1 8 7 4 3], time taken 71.0 minutes
30    route [7 5 2 0 8 1 3 6 4], time taken 73.0 minutes
31    route [3 4 7 8 1 0 2 5 6], time taken 71.0 minutes
32    route [3 4 6 8 1 0 2 5 7], time taken 71.0 minutes
33    route [1 0 8 6 4 3 2 5 7], time taken 89.0 minutes
34    route [3 4 6 7 8 1 0 5 2], time taken 72.0 minutes
35    route [1 8 0 2 5 7 6 4 3], time taken 73.0 minutes
36    route [3 4 6 7 5 2 1 8 0], time taken 77.0 minutes
37    route [2 3 6 4 7 5 0 1 8], time taken 75.0 minutes
38    route [0 5 7 6 4 3 2 1 8], time taken 70.0 minutes
```


Figure 6: Python Output

The districts are numbered as follow:
Garki - 0; GarkII - 1; Wuse I - 2; Wuse IIA - 3; WuseIIB - 4; CBD - 5; Maitama - 6; Maitama II - 7; Asokoro - 8

38 alternatives routes were provided by the python output as shown in figure 6, the best three (considering the time taken) out of them are listed below according to their position.

1. Route 18, time taken 68 minutes is through Maitama I - CBD - Maitama 2 - Asokoro - Garki 2 - Garki I - WuseI - Wuse IIA - Wuse IIB

Route 20, time taken 69 minutes is through Wuse I - Wuse IIA - Maitama I - WuseIIB

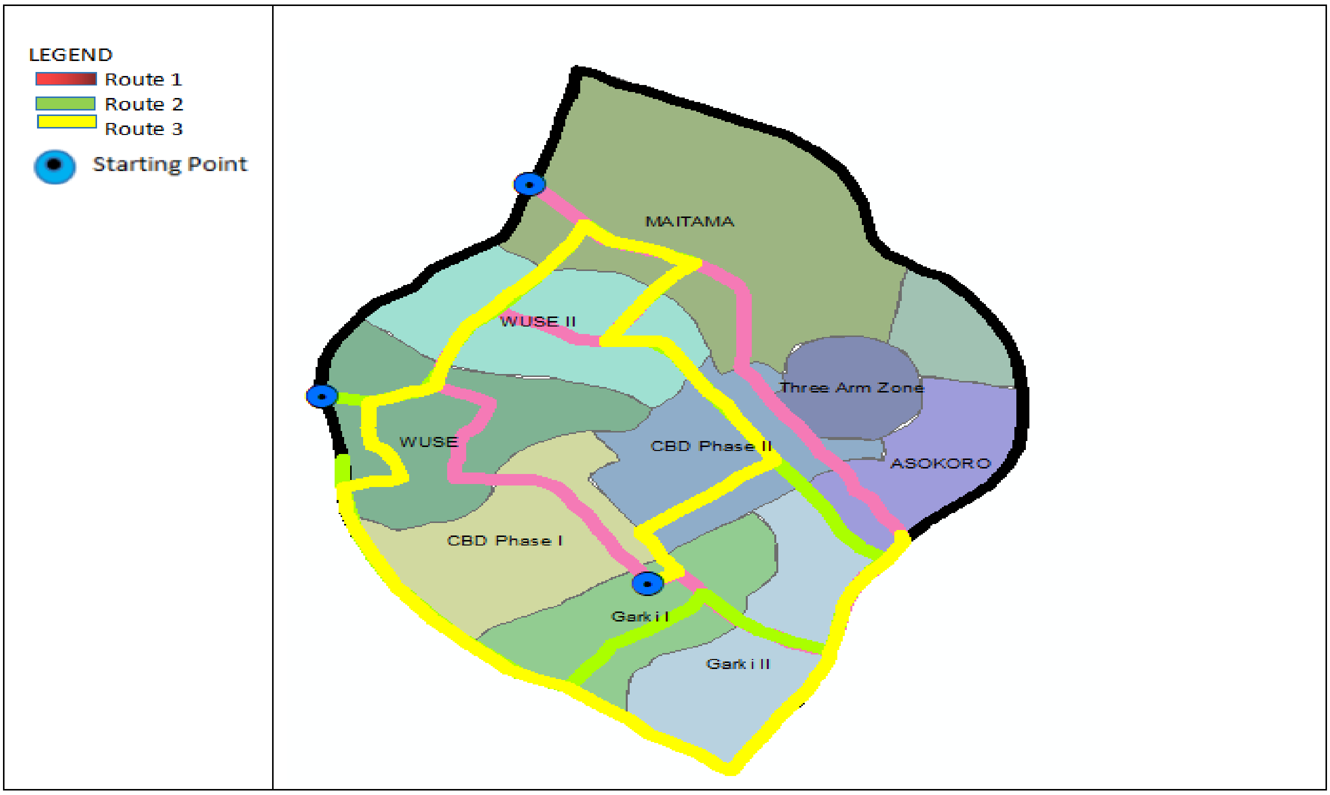

Figure 7: The three best routes

Route 18 is the optimum bus route, it consists of Shehu Shagari way - OSEX - Ahmadu Bello way - Nnamdi Azikiwe Express way - Harbert Macauley way - Kashim Ibrahim way - Ahmadu Bellow way - Ibrahim Babangida way

5.0 CONCLUSIONAND RECOMMENDATIONS

5.1 CONCLUSIONS

The following conclusions were drawn from the results of the data obtained, analyzed and discussions therefrom:

The trip distribution displays the patterns of demand for travel inside the city between various sources and destinations. When deciding where to build or upgrade transportation infrastructure, such as roads, highways, and public transportation routes, this information is crucial. Additionally, it aids in locating potential hot spots for congestion and locations in need of expansion to handle expected increases in travel demand.

Additional bus routes created will improve the accessibility of different parts of the city and neighborhoods. This will lessen transportation disparities and is especially advantageous for locals who might not have easy access to the current transportation options. Moreover it lessens traffic congestion on the highways by offering a substitute for driving a private vehicle.

Optimum bus route determined will reduce travel times for passengers and promotes public transportation use since it's a quicker and more practical choice. For transit agencies, it will also result in financial savings. Operational expenses will be kept to a minimum by cutting up on needless travel and fuel usage. The sustainability of public transportation networks depends on this efficiency.

5.2 RECOMMENDATIONS

Adequate public buses and bus stops at an ideal spacing of 400 meters should be provided for use in the City. This will limit the use of private automobile for public transportation. The optimal bus route network provided in this study should be implemented to solve the problem of accessibility to public transport bus services and for effective operation of the system in the City. The travel time of the optimum bus route within the city is 68minutes which is very high; thus, the authority should demarcate bus routes along the highway in order to improve safety, efficiency and accessibility of the bus to the people and encourage the use of public transport.

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