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Lagos Waterways and Road Transport in a Bridal Match for Sustainable Transport Development in Lagos Metropolis

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Abstract: One of the factors affecting the quality of life in Lagos Metropolis is the search for ways to relieve traffic congestion and reduce travel time. In view of this, it becomes pertinent to develop a framework for efficient utilization of the existing waterways as a complement to road transportation in Lagos. This paper attempts to design a framework with operational objective functions that take into account passengers, travel distance, route geometry, travel time, and capacity on road and water transportation system in Lagos State. It is done with a view to creating an efficient and enhanced transportation system framework for Lagos State using Geospatial Information System. Hence, the formulation for evaluating water mode of transportation based on graph theory, spatial interaction and urban transit capacity is presented. The underlying network of the problem is defined by nodes and network arcs. The adjacency matrix records time and distance data for each pair of points and maps a two-node polyline connecting the endpoints. However, constraints such as vehicle/ferry capacity, travel distance, travel time and water depth were considered for the determination of admissible arcs. To achieve this objective, the required mathematical models were developed (equations 1.6 and 1.8) such that they accept these parameters to determine the link travel time in both cases. From the results and the concluding analysis using bar chart, it was observed that the development of water transport system would help to mitigate the perennial traffic congestion on Lagos roads.

Keywords: Graph theory, congestion, traffic, travel time, adjacency matrix, and spatial interaction.

1. INTRODUCTION

Transportation is the back bone of urban life. Many urban activities are not located together in one place and there is an increasing need for people to travel to work, school, shopping and other places in the city, so as to satisfy their daily needs. To overcome the distance separating them from their activity, they required particular means of movement and those without a personal vehicle must make use of the public transportation for such journey [12]. In Lagos metropolis, traffic is generally characterized by workers moving daily from residential areas (Lagos Mainland) to their work place (Lagos Island). Traders too carry their wares from one part of the city to another, while others go to schools and other business centres. Previous studies have revealed the effects of traffic congestion on Lagos metropolis. Over the years in Lagos State, capacity expansion has been regarded as a major panacea to minimization of road traffic congestion in metropolitan Lagos. Ironically, the construction of new roads and expansion of old ones by successive administrations in Lagos has never ameliorated the problem. Demand has always superseded supply, because vehicular volume for passengers and human population in Lagos has continued to increase daily [1, 6] found evidence in U.S. cities for the fundamental law of road congestion (i.e., that transport volumes increase proportionally to highway capacity, so that building extra capacity does not reduce congestion levels). They found that between 1983 and 2003 individual as well as commercial traffic increased with the stock of roads in a city and that cities with less congestion attracted people. This implies that an increase in the volume of urban road transport is partly generated by new road capacity. This congestion has a negative feedback on the volume of demand. The effect of congestion on the volume of transport demand and the policies to address congestion are relatively well understood by economists [20].

Global transport volumes will grow very rapidly, but growth rates differ between modes and across regions, as indicated by the following orders of magnitude [7, 8]. Road use by light-duty vehicles (measured in vehicle-km) is expected to be 2.5 times as high in 2050 as it was in 2000, while road use for freight could grow by a factor of five during the same time frame. Air transport services (measured in passenger-km) are expected to grow fivefold as well. Growth will be particularly fast outside the Organization for Economic Cooperation and Development (OECD), notably in emerging economies, including China. As a result, whereas in 2005 traffic activity (passenger-km and ton-km) in OECD countries was at about the same level as in non-OECD countries, in 2050 non-OECD traffic activity is expected to be 2.5 times as high as OECD traffic activity [7]. The main driver of growth outside the OECD is in the passenger-km segment. In emerging economies, rapid income growth, and in some cases also population growth,

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translates into very rapid growth of car ownership levels. Ownership levels reach about 350 cars per 1,000 inhabitants in Russia and Latin America, for example, and about 250 cars per 1,000 inhabitants in China, India, and Southeast Asia [7]. In the OECD, lower income and population growth and already high ownership levels are expected to translate into slower growth of vehicle stocks. According to [21], while Nigeria's population density is 100 persons per square kilometre(psk), that of Lagos is about 2,400 person/km^2 with annual population growth rate of between 5.0 to 5.5%.

[17] stated that car travel in the United States, measured in vehicle-km, stopped growing in recent years and argued that this is the result of not only higher fuel prices but also saturation of demand (i.e., even with higher incomes or lower prices the demand for transport would no longer increase). [4] draws a similar conclusion for France but stated that slower or zero growth in car transport volumes does not mean that overall transportation demand has stopped increasing. Instead, he shows that faster modes of transport, such as high-speed rail (HSR) and air transport continue to grow as incomes rise because they allow consumers to squeeze more, and more spatially dispersed activities into the time budget. Although the jury is still out on whether car travel has actually stopped growing in advanced economies, and, if it has, whether this is because of saturation of demand for travel, higher fuel prices, or some combination of these factors, it is likely that car travel volumes will grow slowly or not at all in advanced economies and grow rapidly in emerging economies. The overall conclusion of the projections is that there will be considerable growth in global car transport volumes, especially outside the OECD. Within the OECD, particularly strong growth is foreseen for faster modes (air and HSR). Freight transport is expected to grow more strongly than passenger transport.

Although urban transport accounts for a small share of overall passenger transport (about 20 percent), congestion and air pollution problems are more acute in urban areas than elsewhere. Urban transport also relies on more modes of transport than transport in non-urban areas. Urban transport modal shares vary greatly across countries. One of the most striking differences is the small share of private motor vehicle trips in European and Asian cities compared to many North American cities. For example, private motor vehicle trips account for 20 percent of all trips in Hong Kong, 30 percent of all trips in Amsterdam, 45 percent of all trips in Berlin, 50 percent of all trips in Rome, 90 percent of all trips in Calgary, and 95 percent of all trips in Houston ([7], p. 206, using data from the UITP Millennium Cities Database). In Lagos metropolis private motor vehicle account for 25% of all trips, while Danfo bus account for 57% Okada account for 8%, Molue bus account for 5%, Bus Rapid Transport which started in March 2008 account 4%, Rail account for 0.70%, and paltry share 0.03% went for water transport.

Investment in urban public transport and even its operating costs are generally subsidized in OECD countries. The main justifications for these subsidies are the economies of scale and the fact that the external congestion and air pollution costs of car use in urban areas are not reflected in user prices. The optimization of public transport fares suggests that there should be high subsidy rates when the external costs of car use are not reflected in car use costs [15, 13]. However, high subsidies do not guarantee a high-performing urban public transit system. Experience with public transport subsidies has been mixed, resulting in a fierce debate among economists concerning their effectiveness. For example, [23] found that the U.S. public rail systems are heavily subsidized but not welfare improving, with the exception of the Bay Area Rapid Transit system in San Francisco. In many countries, light rail systems have been absorbing a disproportionately large share of public transport investments but without solid economic justification [14].

However, the transport sector also causes flow-type externalities that threaten our current way of life. If urbanization continues and economic activity is concentrated in ever larger metropolitan areas, congestion levels could become intolerable. In addition, levels of noise and pollution remain problematic despite advanced emissions control technology. There is evidence to suggest that these flow externalities are quantitatively at least as important as the transport sector's climate and energy resource impacts [19, 16]. Passengers' choices concerning their modes of transport have implications for many transport externalities. For example, a car with one passenger has an external congestion cost per passenger that is about ten times as high as a bus with twenty-five passengers because a bus has the same congestion effects as 1.5–3 cars [2]. Assuming sufficiently high occupancy rates, a bus also uses less fuel and has lower accident costs per passenger. The air pollution cost per passenger of rail transport depends on the occupancy rate and on the type and amount of fuel used. With a high occupancy rate, rail has almost no external costs except for the congestion costs among the rail passengers and rail freight and the external noise costs.

The present market shares of different modes of passenger transport differ greatly across countries. For example, in China and India, private passenger cars had a market share (in terms of passenger-km) of less than 20 percent in 2005 (IEA 2009). Minibuses, buses, rail, and air accounted for the remainder of the market. In contrast, in OECD Europe, private passenger cars account for 65 percent of total passenger transport volume, and bus/rail and air each account for about 15 percent of the total. In North America, cars account for approximately 80 percent, bus and rail 5 percent, and air transport 15 percent of the passenger transport market [7]. There are three main drivers of modal choice for passengers [5]: income levels, relative user costs (including time costs), and public policy.

Road transport currently plays a very important role in Lagos Metropolitan transport system. Water transport is also important and relevant in Lagos, because it costs less compared to the road transport system [22], therefore it requires less investment. Moreover, water transportation system offers an economic and eco-friendly mode of transport, particularly for the movement of bulk cargo and passengers, but the inland waterways have remained the most neglected segment of the transport system in Lagos. Transportation is central to the flow of knowledge, information and commercial goods. The type of available transport system, and how they are used, tell a great deal about a society and its values. All international transport modes have managed to reduce their transport prices over the past 20 years. Road, rail and water transport have done a 36 %, 45 % and 52 % reduction in their transportation prices respectively.

IWW transport is the cheapest mode followed by rail and road, however, it is not enough to attract more customers and achieve a greater share from the modal split. Transport energy consumption increased by 22 % between 1990 and 2000. Emissions of greenhouse gases (GHG) from transport increased by 21% between 1990 and 2001, contributing to a fifth of the total GHG emissions in 2001 in the EU. The main contributor to transport GHG emissions is CO_2 (97%) and road transport is, in turn, the largest contributor to these emissions (92% in 2001). It is the largest energy consuming sector, being responsible for about 35% of the total energy consumption in 2000. Aviation is the sector's fastest growing energy consumer and road transport is the biggest. From this absolute point of view inland navigation performs best [9]. Many studies indicate that noise produced by ships, as compared to other transport modalities (trucks, planes, trains) is not considered as relevant. Consequently only noise impacts of these other modalities have been described in literature [3]. According to different references based on the statistical data, the number of fatalities and severe injuries in IWW are not relevant to the other transport modes. Hence, it can be stated that inland waterway navigation is still the safest transportation mode. From this it is obvious that IWW transport is still in a good position considering sustainability [9]. For sustainable transport development the necessity of modal shift is inevitable and the inland waterway navigation should get the higher share of the total transport in coastal cities like Lagos State. Since most of the waterways are natural, it seems that the infrastructure cost of inland navigation is rather small. On the other hand, for fair comparison it should be noted that for effectively navigable rivers dams and locks and maintenance work (dredging) are needed. Congestion is the largest component in many urban areas.

Lagos is known not only as a centre of commerce and investment but also for severe traffic congestion problems. Ikorodu Road, Western Avenue, Badagry Express Way, Epe Express Way and Third Mainland Bridge are always congested in the morning and in the evening. Transportation in Lagos State is usually chaotic. This is because six million passengers hustle daily between Lagos mainland and island. The mini buses that convey them are not regulated. The drivers are not trained; Lagos has the highest vehicular density of 222 vehicles per kilometre [11].

However, the negative effect of road transport activities on the environment includes the damage done to the environment. Among others are; poor visual impression and aesthetic implications, transport-induced environmental pollution (noise, atmospheric and water), parking problems, vibration, displacement, severe accidents and traffic congestion/ peaking period traffic disturbances. Inland waterways sector has always been neglected to the detriment of the navigable rivers in the country and the riverine dwellers. It is in view of this perennial oversight even by state governments with riverine areas that prompted this research. The main focus of this study is to develop a framework for the efficient utilization of water transport system in Lagos lagoon as a complimentary mode to the road transport system. The objectives of the paper are to prepare navigation charts exhibiting the depths along the proposed transit routes, and to estimate the average travel time (peak, off-peak), travel distance, average passenger loads (peak, off-peak), and capacity for water and road transport system. The findings of this research shall be of great relevance to both the Federal and State Governments and citizenry. Some of the benefits derivable from the study will include: diversion of traffic to waterways would in turn provide relief to roads in Lagos State and consequently improved lifespan of roads, It would minimise problems of environmental pollution arising from emission of GHG and noise from people and vehicles and significant savings in travel time will be attainable if properly managed. This research is limited to the conceptual design of ferry transit network for sustainable transportation system in Lagos State based on the available bathymetric survey data in a GIS environment. In addition, the effect of tidal seasonal variability, were also considered in the analysis.

2. METHODOLOGY

The methodology adopted in this research considered the need to complement travel demand on road with water transport system. A simple model showing basic interactions between three essential components of complement travel demand in Lagos Metropolis is given by;

$$I_{ts} = C_{nr} + I_{nf} \tag{1.0}$$

where:

I_{ts} = Integrated Transport System

I_{nf} = Idle Navigable Fairway

C_{nr} = Congested Narrow Road

If an integration is carried out on the above formula, then the enhanced transport solution could become panacea to the perennial traffic congestion on Lagos road. Let represent the decongesting properties of waterways as a result of the number of persons removed from the roads, in turn proportional to waterway, with a constant of proportionality, α.

$$Q = Q_c + \alpha Q_w \tag{1.1}$$

where

Q= Flow which consist of congesting road and non congesting waterways

Q_c= Congested Narrow Road Flow

Q_w= Non congesting Idle Navigable Fairway Flow

In line with the objectives of the study, data required are in respect of the following information:

- Bathymetric survey data
- Route length
- Socioeconomic characteristics of the commuter;
- Traffic characteristics;

The bulk of the data required were collected between June 2006 and December 2010. Data were obtained from field survey using hydrographic survey technique and additional data were collected with the aid of questionnaires on both operators and commuter. The hydrographic data were collected from the following source:

i University of Lagos, Department of Surveying and Geo-Informatics: Bathymetric Survey of part of Lagos Lagoon from {Hamzat, (2006), Azzez, (2007), Adejare, (2007, 2008, 2009).

ii. Hydrographic Department, Nigeria Port Authority: Bathymetric Survey of Lagos Harbour.

iii Global Positioning System (GPS) coordinates determination of some point features such as existing jetty's.

For questionnaire administration, the following information was considered, the time of day and day of the week that represents the actual situation as well as logistic needed for effective study. For easy questionnaire administration, the study area was divided into four separate zones based on very high density of demand on both the origin and destination side. The zonal boundaries were determined by the transport network, trip generation and trip attraction. Also, the hydrographic surveys data acquired from the above sources were determined using echo sounder. Global positioning system was used to determine the plannimetric coordinate of the sounding locations concurrently with the sounding exercise.

Land use analysis is a convenient way to study the activities that provide the basis for trip generation because travel patterns (routes and traffic flows) are dictated by the transportation network and land use arrangements. It must be stated here that a trip is an event linking an origin (home) and a destination (place of work). It is performed by travelling on a defined route, which has a certain length in kilometre and takes a certain time to travel. Therefore the land use map of the study area was also obtained from Lagos State Planning Section. Lagos Street Map was obtained from the Department of Surveying and Geo-informatics, Faculty of Engineering, University of Lagos, while the Lagos Lagoon was extracted from the Google earth image all this maps were acquired in softcopy.

2.1. Data Processing

The measured depths were automatically generated from the echo row which was later processed to true depth by the removal of the tidal effect. The true depths were extracted from sounding data as described below;

Sounded Depth (SD): These are the raw depth acquired by echo sounder without the removal of tidal effect and chart datum.

True Depth (TD): This is the real value of the depth of the sea floor. It was obtained after applying all the correction and removal of all other phenomenon that contributed to the raw data obtained from sounding.

$$TD = SD - d + (MSL - TO) \quad (1.2)$$

- Sounded depth at a certain time recorded = SD
- Tidal Observation of that time of depht observation. = TO
- The mean Tide level (M. T. L) = M. T. L
- Chart datum = d

The bathymetric and positioning data were plotted in AutoCAD software environment and later transferred into ArcGIS where it was superimposed on the Lagos Lagoon map. This provides the composite map of the study area.

2.2, Model Formulation for the Research

A graph is an ordered triple (V(G), E(G), ψ(G) consisting of a nonempty set, V(G) of vertices, a set E(G), disjoint from V(G), of edges, and an incidence function ψG that associates with each edge of G an unordered pair of (not necessarily distinct) vertices of G. If **e** is an edge and **u**, **v** are vertices such that ψG (e) = uv, then **e** is said to join u and v; the vertices u and v are called the ends of e. The representation below serves the purpose of clarification for this research work.

$$G = (V(G), E(G), \psi G), \quad (1.3)$$

where

V(G) = {Lagos central(Marina), Badagry, Ikorodu, Epe, Apapa Wharf, Mile 2, Festac Town, Oyingbo, Ijora, Awolowo Road(ikoyi), Ebute Ero, Akoka, Oworonsoki, Queens Drive, Victoria Island, Badore} = $\{v_1, v_2, v_3, v_4, v_5, v_6, v_7, v_8, v_9, v_{10}, v_{11}, v_{12}, v_{13}, v_{14}, v_{15}\}$

E(G) = {e/e link between two locations: $e_1, e_2, e_3, e_4, e_5, e_6....e_n$} and ψG is defined by

$\psi G(e_1) = v_1 v_2, \psi G(e_2) = v_2 v_3, \psi G(e_3) = v_3 v_4, \psi G(e_4) = v_1 v_4, \psi G(e_5) = v_1 v_3, \psi G(e_6) = v_2 v_4$

2.3. Estimation of Link Travel Times

Total link travel times are the sum of two components transportation time and dwell time.

$$T = \sum T_t + \sum t_d \quad (1.4)$$

where

T_t is travel time to traverse the link at cruise or congested speed (in minutes).

t_d is the travel time loss due to dwell time.

Travel times were estimated using the Popular Bureau of Public Roads volume/delay function. That is, the travel times on each link with flow is related to the free-flow travel time and capacity as follows using equation (1.6) for water route;

$$T = \left[\frac{L}{u}\right] * 60; \quad (1.5)$$

$$T = \left[\frac{L}{u}\right] * 60 + \left(P_a t_a + P_b t_b + t_{oc}\right) \quad (1.6)$$

where: L = is the link length in Kilometers; u = speed limit in kilometers per hour; 60 = conversion factors from hours to minutes; P_a, = alighting passengers per bus through the busiest doors during peak 15-min (p); t_a = passenger alighting times seconds per passengers (s/p); P_b, = boarding passenger per bus through the busiest doors during peak 15-

min (p); t_b = passenger boarding times (s/p); t_{oc} = door opening and closing time (s).

On the road link traversal time due to congestion is estimated based on the equation (1.8);

$$T = \left[\frac{L}{u}\right]\left[1.0 + 0.45\left(\frac{v}{c}\right)^{5.5}\right] * 60 \qquad (1.7)$$

$$T = \left[\frac{L}{u}\right]\left[1.0 + 0.45\left(\frac{v}{c}\right)^{5.5}\right] * 60 + \left(P_a t_a + P_b t_b + t_{oc}\right) \qquad (1.8)$$

where; L = is the link length in Kilometers; u = speed limit in kilometers per hour

60 = conversion factors from hours to minutes; v = link volume; c = link capacity

In general, transportation process embraced the total costs of carriage and time expended,

$$Y = \sum \subset + \sum T \qquad (1.9)$$

where; Y = is the costs of transportation; $\subset$ = consists of cost of fuel & oil, cost of maintenance, repairs and labour cost; T = is the total transportation time

The relationship describing transportation by road is such that the costs of transportation are calculated by determining the tariff of carriage by car, and bus using the equation (2.0).

$$C_r = k_r \cdot C_t \cdot L \qquad (2.0)$$

k_r = is the costs of carriage by road transportation system; C_r = road transport capacity (person /hr)

The relationship describing transportation by water is such that the costs of transportation are calculated by determining the tariff of carriage by ferry, and barge using the equation (2.1).

$$C_w = k_w \cdot C_t \cdot L \qquad (2.1)$$

k_w = is the costs of carriage by water transportation system

C_w = water transport capacity (person /hr)

$$C_t = C_a + \alpha C_b \qquad (2.2)$$

C_t = total passenger capacity per vehicle

C_a = vehicle seating capacity

C_b = vehicle standing capacity

α = fraction of C_b allowed

In travel demand forecasting, mode usage come after trip distribution because the information on where trips are going allows the mode usage relationship to compare the alternative transportation services competing for users. Three factors are considered in mode usage analysis as follows:

(1) The characteristics of the trip maker (e.g., income, number of autos available and residential density).

(2) The characteristic of the trip (e.g. trip distance, time of the day).

(3) The characteristics of the transportation system (e.g. riding time, excess time).

The basic model connecting vehicles/vessels, person/goods, and the built infrastructure is shown in the figure below.

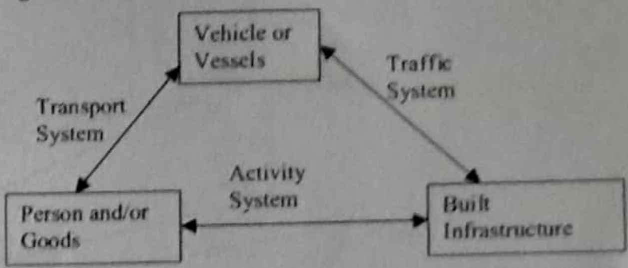

Fig. (1). A Basic Model Connecting Vehicles/Vessels, Person/Goods, and the Built Infrastructure (adopted from Khisty and Lall, 2008).

Fig. (1) above is a simple model showing basic interactions between three essential components namely;

(1) Persons and/or Goods that need to be transported

(2) Motor Vehicles or water Vessels that are used to move people and/or goods

(3) The infrastructure which includes a variety of fixed installation such as roads, bus stops/terminals, airports, and harbour.

- The activity system comprises the movements of persons and goods between two or more points or positions in space relative to the infrastructure.
- The transport system consists of persons and goods needing some kind of vehicle or vessel to move them from one position to another.
- The traffic system in this case, actual physical movement of transport is realized in space and time, assuming that people and goods move together with the means of transport (i.e, vehicles) along physical networks. Each vehicle (or a set of vehicles physically connected to one another) is seen as a traffic unit, and the resulting flow is normally measured as the number of vehicles per unit of time on a specific link of the infrastructure, and in effect, utilizing (or occupying) a certain part of the infrastructure for a specific time (Sjostedt, 1994)

2.4. Water Route Network Design

For the purpose of this research, the composite map was used for selection of the optimal route for the proposed water transport system in the study area. The design framework is as shown below;

2.5. Numerical Evaluation

In order to evaluate the performance of the designed route, the Lagos street map as well as the Bathymetric map of the Lagoon were used to extract the inter nodal distances, on water route cruise speed was adopted while the average speed was adopted for the ground route. Also the maximum delay time of 15 minutes was used for passenger boarding and alighting at pickup point and delivery point. These parameters were used in model 1.6 and 1.8 respectively to compute the link travel time on water and road. Using the

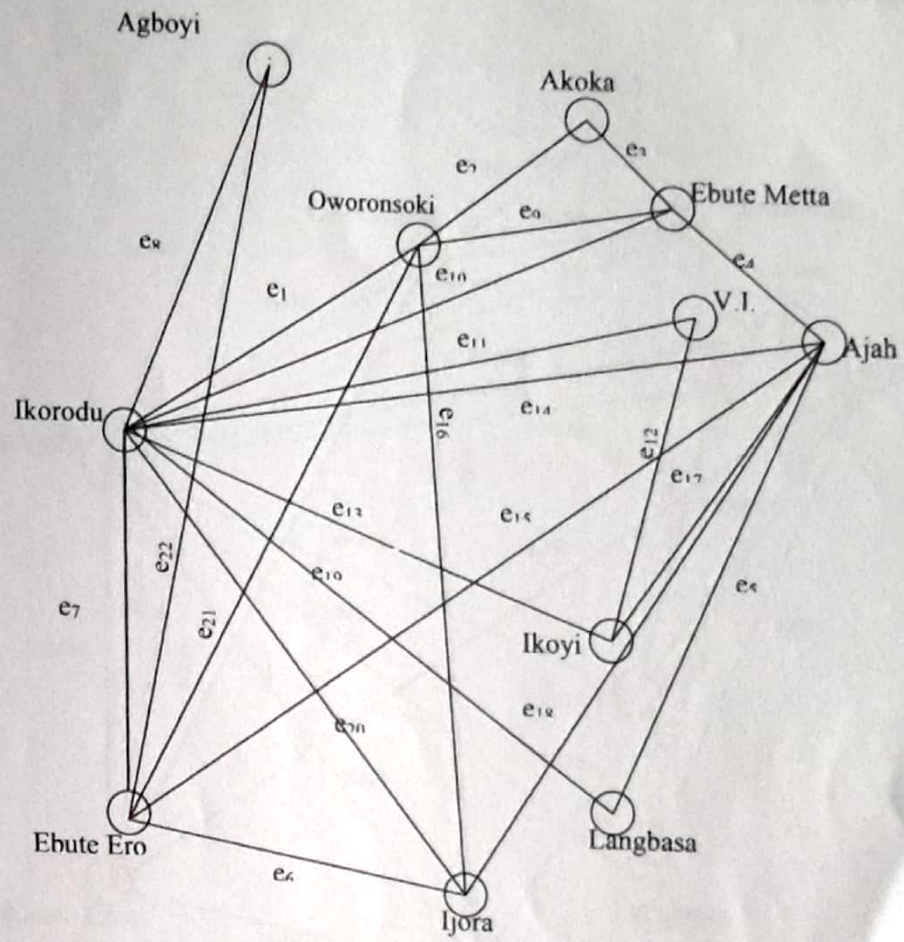

Fig. (2). Lagos Lagoon network design for the proposed water route transport system.

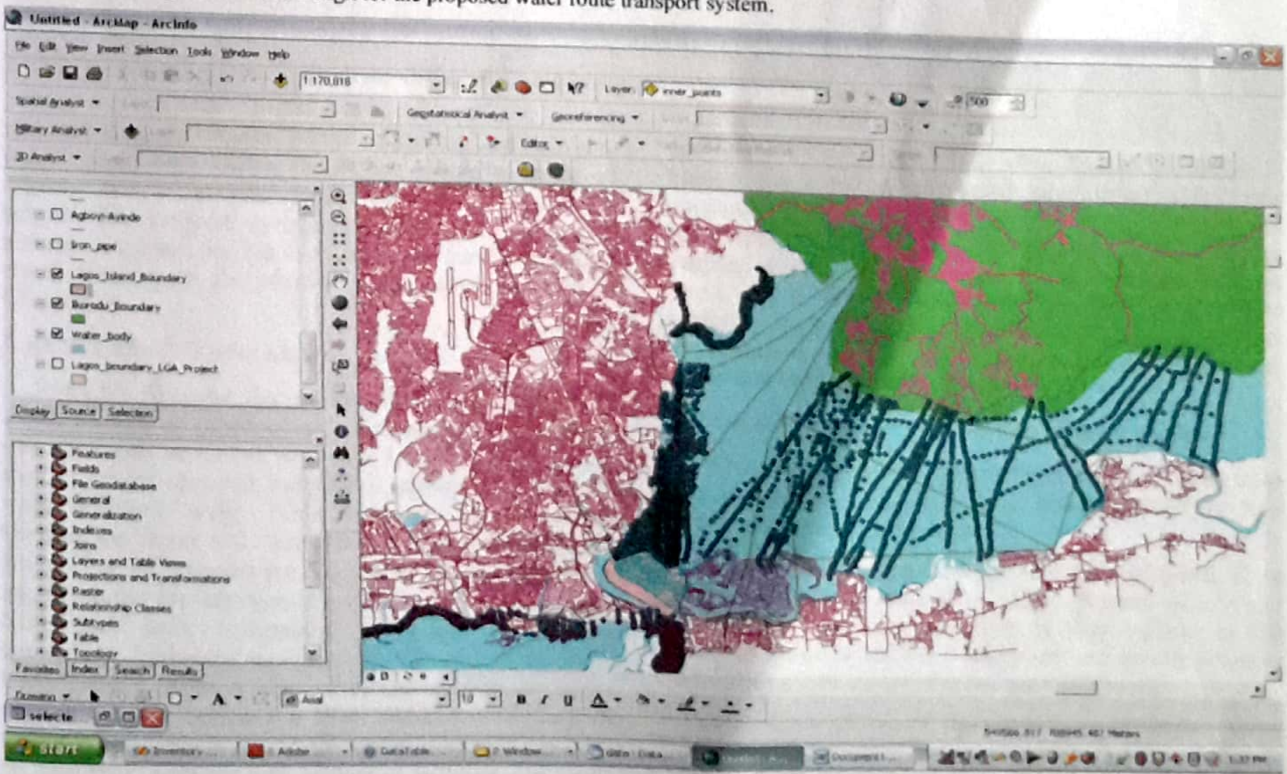

Fig. (3). Bathymetric Chart Displaying Water Depth and existing Road network in Lagos Metropolis.

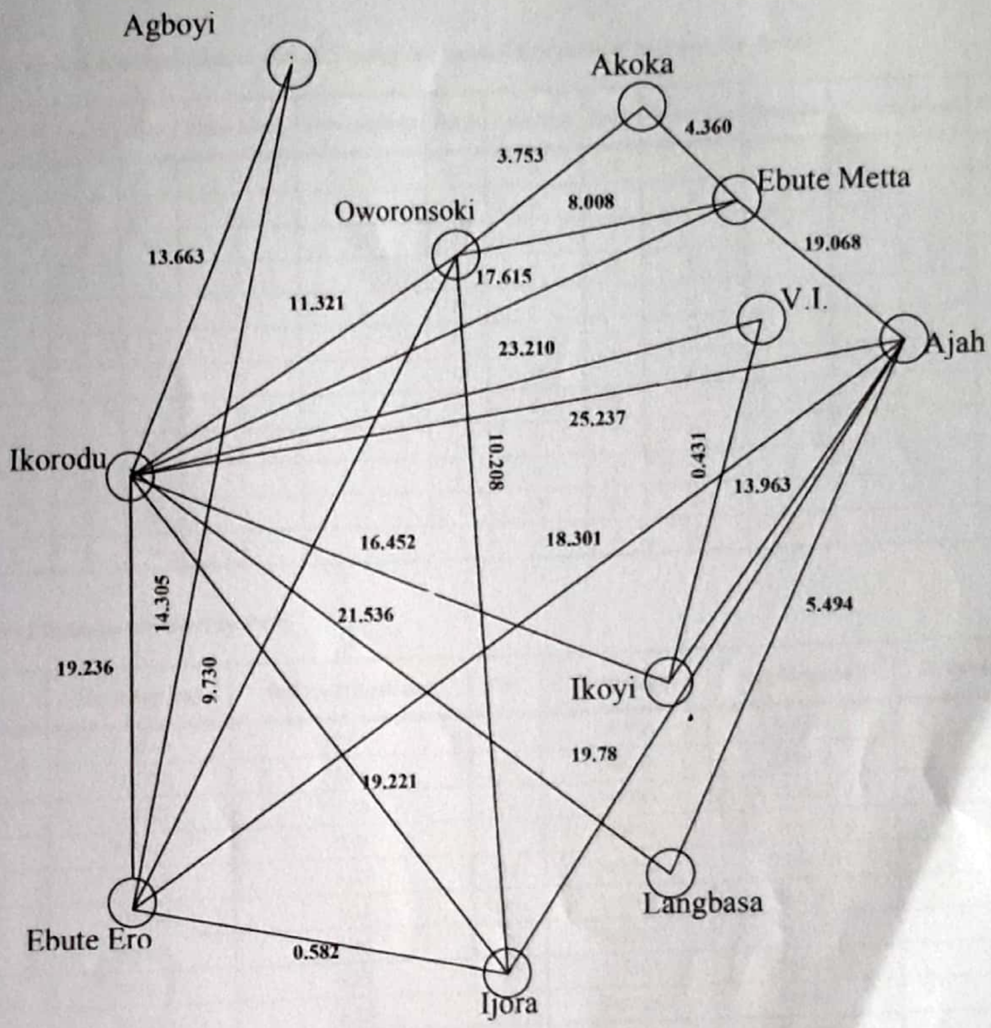

Fig. (4). Lagos Lagoon network design showing the distance between the nodes.

extracted distance between points of pick-up and delivery, vessel speed, total sailing time from pickup to point of delivery and of course; depth, the partial comparison between the transport systems was performed. Fig. (**4**), however depicted the resulting network from the design where numbers on the edges represent travel distance in Kilometres.

3. RESULTS AND ANALYSIS

From the foregone figures, the adjacency matrix which shows a matrix of existence and relationship between nodes was generated as shown in Table **1**, Table **2** shows the abstract of the acquired bathymetric survey data used for route selection, while Table **3** shows the comparison between the Road and Water routes distances. From the design (Fig. **4**) networks are reduced to the level of graphs. Fig. (**4**) shows the reduction of a simple road/ water network (with each node representing an origin, intersection, terminal, or settlement on the route) to a system of nodes, links. Table **1** shows a series of binary matrices for nodes, links in which 1 represent a direct connection between the elements and 0 otherwise. These connectivity matrices could be incidence matrices and adjacency matrices for spatial interaction between the jetties were derived as shown in Table **1**. The acquired bathymetric survey data (Table **2**) was obtained in order to create organized graphic portrayal (geographic and textual data) of the marine environment for nautical charts, showing the nature and form of the lagoon areas, depth of the water and general character and configuration of river bed, identification/locations of dangers to navigation, rise and fall of the tides and cautions to man made aids to navigation in the lagoon.

3.1. Determination of the Mode Carrying Capacity

The passenger- carrying capacity of an urban transit route was computed using equation 2.2 which account for total passenger capacity per vehicle.

Traffic survey along the major routes revealed that, Third mainland, Ikorodu road, Eko bridge, Western avenue and Agege motor road are often used by these vehicles in that order as shown in Table 5. These routes are directly linked to all the identified industrial areas and CBD zones.

The times of arrival from origin to destination using equation 1.6 for water mode and equation 1.8 for road mode were estimated and the results obtained for each route were

Table 1. Adjacency Matrix Manipulation in Graph Theory for Spatial Interaction between the Jetties

Jetty Name	Agboyi	Akoka	Ajah	Ebute Metta	Oworonshoki	Ikoyi	Langbasa	Ijora	Ebute Ero	Ikorodu	Victoria Island	Row Summary
Agboyi	0	0	0	0	0	0	0	0	1	1	0	2
Akoka	0	0	0	1	1	0	0	0	0	0	0	2
Ajah	0	0	0	1	0	1	1	1	1	1	0	6
Ebute Metta	0	1	1	0	1	0	0	0	0	1	0	4
Oworonshoki	0	1	0	1	0	0	0	1	1	1	0	5
Ikoyi	0	0	1	0	0	0	0	0	0	1	1	3
Langbasa	0	0	1	0	0	0	0		0	1	0	2
Ijora	0	0	1	0	1	0	0	0	1	1	0	4
Ebute Ero	1	0	1	0	1	0	0	1	0	1	0	5
Ikorodu	1	0	1	1	1	1	1	1	1	0	1	9
Victoria Island	0	0	0	0	0	1	0	0	0	1	0	2
Column Summary	2	2	6	4	5	3	2	4	5	9	2	44

Table 2. Abstract of Bathymetric Survey Data

S/N	Eastings (m)	Northings (m)	Reduced Depth (m)	S/N	Eastings (m)	Northings (m)	Reduced Depth (m)
1	543741	716511	2.94	30	543754	715471	6.25
2	543775	716371	1.74	31	543755	715462	6.25
3	543735	716357	1.74	32	543755	715452	3.75
4	543735	716344	0.74	33	543758	715412	3.15
5	543738	716246	1.25	34	543760	715402	3.15
6	543739	716231	1.25	35	543761	715381	3.75
7	543740	716214	1.25	36	543763	715347	4.65
8	543743	716180	5.25	37	543764	715329	4.65
9	543743	716173	5.25	38	543765	715308	3.55
10	543744	716162	5.75	39	543765	715276	3.4
11	543745	716151	5.75	40	543764	715202	2.75
12	543749	716118	4.35	41	543764	715187	2.75
13	543752	716090	4.35	42	543765	715154	1.65
14	543753	716081	3.75	43	543766	715138	1.7
15	543753	716073	3.75	44	543767	715119	3.45
16	543760	715985	2.25	45	543767	715107	4.65
17	543760	715980	2.25	46	543768	715076	5.05
18	543759	715878	2.55	47	543767	715024	5.95
19	543760	715886	2.55	48	543766	714991	8.65
20	543765	715811	1.25	49	543767	714979	9.7
21	543765	715797	1.25	50	543767	714939	11.15
22	543765	715758	0.85	51	543774	714878	10.95
23	543765	715753	0.85	52	543777	714820	8.6
24	543764	715707	1.75	53	543776	714812	6.55
25	543764	715695	1.75	54	543777	714781	6.55
26	543763	715634	4.65	55	543776	714757	2.55
27	543763	715625	4.65	56	543778	714711	1.85
28	543761	715604	4.65	57	543782	714671	1.85
29	543754	715482	6.25				

Table 3. Comparison of Road and Water Transportation Routes Distances

Route Name	Water Route Distances (Km)	Road Route Distances (Km)
Oworonshoki-Ebute Ero	9.73	11.672
Oworonshoki-Ijora	10.208	23.12
Ikorodu-Ebute Ero	19.236	32.172
Ikorodu-Ijora	19.221	31.171
Ebute Ero- Ijora	0.582	1.148
Oyingbo – Ebute Ero	1.23	5.846
Oworonshoki- Unilag	3.012	3.939
Unilag Ebute Metta	4.36	5.056
Ikorodu- V.I	23.21	39.958
V.I –Ikoyi	0.431	2.16

Table 4. Travel Time Estimation using Equation 1.6 and 1.8 Respectively

Route Name	Oworonshoki- Ikorodu		Oworonshoki- Ebute Ero		Oworonshoki- Ijora		Ikorodu- Ebute Ero		Ikorodu- Ijora		Ebute Ero – Ijora		Oyingbo-Ebute Ero		Oworonshoki-Unilag		Unilag - Ebute Metta		Ikorodu - Victoria Is.		Victoria Is. – Ikoyi	
Speed (K/h)	Road Travel Time (m)	Water Travel Time (m)	Road Travel Time (m)	Water Travel Time (m)	Road Travel Time (m)	Water Travel Time (m)	Road Travel Time (m)	Water Travel Time (m)	Road Travel Time (m)	Water Travel Time (m)	Road Travel Time (m)	Water Travel Time (m)	Road Travel Time (m)	Water Travel Time (m)	Road Travel Time (m)	Water Travel Time (m)	Road Travel Time (m)	Water Travel Time (m)	Road Travel Time (m)	Water Travel Time (m)	Road Travel Time (m)	Water Travel Time (m)
10	239.0	61.8	127.3	53.1	252.2	55.7	351.0	104.9	340.0	104.8	12.5	3.2	63.8	6.7	43.0	16.4	55.2	23.8	435.9	126.6	23.6	2.4
20	119.5	30.9	63.7	26.5	126.1	27.8	175.5	52.5	170.0	52.4	6.3	1.6	31.9	3.4	21.5	8.2	27.6	11.9	218.0	63.3	11.8	1.2
30	79.7	20.6	42.4	17.7	84.1	18.6	117.0	35.0	113.3	34.9	4.2	1.1	21.3	2.2	14.3	5.5	18.4	7.9	145.3	42.2	7.9	0.8
40	59.7	15.4	31.8	13.3	63.1	13.9	87.7	26.2	85.0	26.2	3.1	0.8	15.9	1.7	10.7	4.1	13.8	5.9	109.0	31.7	5.9	0.6
50	47.8	12.4	25.5	10.6	50.4	11.1	70.2	21.0	68.0	21.0	2.5	0.6	12.8	1.3	8.6	3.3	11.0	4.8	87.2	25.3	4.7	0.5
60	39.8	10.3	21.2	8.8	42.0	9.3	58.5	17.5	56.7	17.5	2.1	0.5	10.6	1.1	7.2	2.7	9.2	4.0	72.7	21.1	3.9	0.4
70	34.1	8.8	18.2	7.6	36.0	8.0	50.1	15.0	48.6	15.0	1.8	0.5	9.1	1.0	6.1	2.3	7.9	3.4	62.3	18.1	3.4	0.3
80	29.9	7.7	15.9	6.6	31.5	7.0	43.9	13.1	42.5	13.1	1.6	0.4	8.0	0.8	5.4	2.1	6.9	3.0	54.5	15.8	2.9	0.3
90	26.6	6.9	14.1	5.9	28.0	6.2	39.0	11.7	37.8	11.6	1.4	0.4	7.1	0.7	4.8	1.8	6.1	2.6	48.4	14.1	2.6	0.3
100	23.9	6.2	12.7	5.3	25.2	5.6	35.1	10.5	34.0	10.5	1.3	0.3	6.4	0.7	4.3	1.6	5.5	2.4	43.6	12.7	2.4	0.2

as shown in Table **4** above. The graphical representation of the results were as shown in Figs. (**2, 4, 5**) respectively, while the water bed topography plotted from the bathymetric data for each route under consideration are depicted in Fig. (**3**) above. Fig. (**5**) depicts the relationship between Travel Distance and Travel Time by Mode, while Figs. (**6, 7**) portrayed the passenger carrying capacity and Tables **6** and **7** showed travel mode carrying capacity on the links. However, Fig. (**8**) depicts the composite base map, which consist of navigation chart, existing congested road network and existing ferry jetties available in Lagos Metropolis. Similarly, a typical setting in Lagos is that the people live in Mainland and work in the Island. To date the main means of transportation is by road and this creates traffic congestion. The situation can be improved if the water transportation is developed. The waterway is naturally available in Lagos and its relationship to Central Business District makes it adequate for use in transportation as supplement to road transport. Water based transportation is especially more effective in Lagos Metropolis, because the origin and destination are water front locations. Ferries services allow travellers to avoid very long trips by private cars, danfo (14), danfo (18), danfo (22), Bus Rapid Transit, taxi, large bus, molue and coaster buses to go to distant river crossings or drive around Lagos Lagoon and harbours. The operation will involve a link to another link, because waterway could not provide door to door services without a complimentary role from land transport.

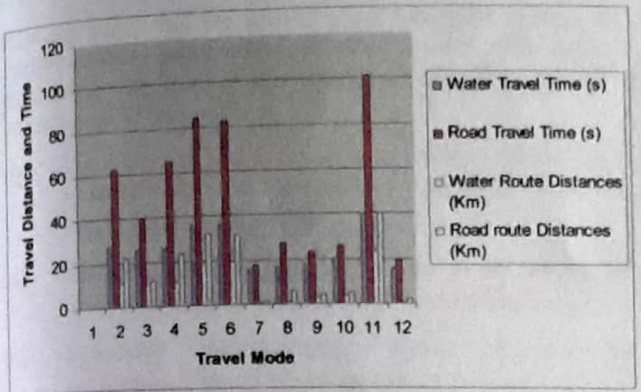

Fig. (5). Bar chart depicting comparative analysis of road and water Travel Distance as well as Travel Time.

Lagos lagoon has many restrictions that greatly, influence navigation. The most important restrictions are the water depth and the bridge height. From the study, the summary of the navigable restriction is given below; **Water depth**: In the lagoon, several sections have water depth less than 3 meters. At the harbour entrance, the water depth is often above 5meter, and the maximum is above 19meter. From the bed topography, many of the ferry terminals require new and maintenance dredging to maintain efficient and effective navigable waterways for the intending ferry services. **Bridge height**: The most critical bridge height are Third mainland bridge, Eko bridge and Carter bridge, with bridge height ranging from 4.70m to 6.40 meter respectively. **Vessel draught**: Taking into account that inland waterways vessel draught should be less than water depth, as well as air clearance; currently in Lagos lagoon, the navigable draught is >1.7m. From the bed topography, the available water depth is adequate for the following vessel draught <1.7m, 2.25m- 2.5m, and 1.5- 1.85m, for ferry services within the lagoon and adjacent creeks. However, larger vessel will have larger deck area, allowing larger number of passenger or vehicle, but the draught will still be more or –less the same.

From the above figures and tables, in the absence of congestion, the travel time and travel distances on water are shorter than the road transport; which accounted for the delay usually experienced on the road transport system in Lagos. However, in view of this, it could be inferred that the water transport system is more environmental friendly and cost effective than the existing road routes. The benefit of developing the inland waterways for optimum transportation system has been highlighted. It has also been made clear

Table 5. 12 h Traffic Count on Selected Roads in Metropolitan Lagos (LAMATA, 2008)

S/N	Roads	Nos. of Vehicles in Both Direction (12 h Traffic Counts)
1	Third Mainland Bridge	220,190
2	Carter Bridge	50,962
3	Eko Bridge	150,130
4	Western Avenue	110,190
5	Murtala Mohammed Way	21,302
6	Herbert Macauley Way	88,345
7	Ojuelegba- Mushin	56,345
8	Ikorodu Road	300,238
9	Agege Motor Road	60,123

Table 6. Passenger Carrying Capacity on the Road

Types of Vehicle	Seating Ca	Standing Cb	Total Capacity Ct
BRT	46	36	82
Private Cars	1.5	NIL	1.5
Taxi	1.5	NIL	1.5
Danfo	14	NIL	14
Urvan	18	NIL	18
Molue	36	11	47
Mb911	56	16	72
1414 Bus	62	26	88
Bedford 1200	42	12	54
Nissan Civilian	26	6	32
Total			414

from the study that the use of water transport system as a complement to road transportation system will enhance productivity because of the benefit of time maximization. The benefits of less traffic:

(i) Time saving: The precious time being spent in traffic hold-up can be channelled towards economic development of the state.

(ii) Reduction in accidents: The rate of accidents will drop considerably with an improved traffic flow.

(iii) Economic development: Good transportation accelerates rate of development of a nation. So free flow of traffic is beneficial to economic development of the state.

(iv) Reduction in vehicle operating cost: With an improvement in traffic flow, vehicular operation cost will be reduced to a considerable amount. This is because the roads being much more motorable help against unnecessary pressures on the vehicle tyres the engine as well as the general body of the vehicles.

(v) Comfort and convenience: Motorist feel more comfortable when there is no interference on their flow and this gives value of good health.

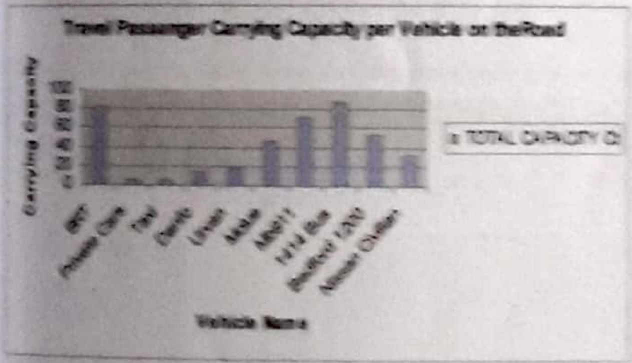

Fig. (6). Passenger Carrying Capacity per Vehicle on the Road.

4. CONCLUSION

This research evaluates the use of passenger ferry service on the Lagos Lagoon. The analysis includes travel time, travel mode carrying capacity, vessel types, facilities, services frequencies and other operational requirements to meet travel demand for commuter passenger service. The availability of Lagos lagoon around Lagos metropolitan area offers an opportunity to encourage water transport as a viable alternate mode of transport. In Lagos Lagoon water carriage is much more important because of the vast system of navigable waterways, the accessibility to major population centers provided by water routes, and the relative shorter distances between origins and destination. A transportation system model of two complimentary forms of transport were considered and compared to maximize the benefit of bimodal transportation services in Lagos Metropolis. In this study, the travel time calculations were used to evaluate water transit as a peak-hour commuter service that would complement existing bus, taxi, car and help to reduce demand for vehicle travel between Lagos central and other population settlements using mathematical model in a vector based GIS to generate enhanced transport planning in Lagos metropolis. From the above it is obvious that inland waterway navigation is still a very environment-friendly, safe, and effective transportation mode as it was known for a long time.

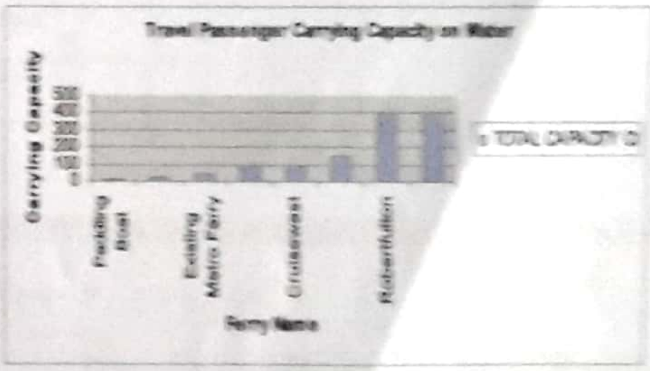

Fig. (7). Passenger Carrying Capacity per Vehicle on the Water.

ACKNOWLEDGEMENT

None declared.

CONFLICT OF INTEREST

None declared.

Table 7. Passenger Carrying Capacity on the Water

Types of Ferry	Seating Ca	Standing Ch	Total Capacity Ct
Paddling Boat	12	2	14
Speed Boat	23	NIL	23
Existing Metro Ferry	45	NIL	45
Water Bus	92	NIL	92
Cruisewest	96	NIL	96
Catamaran	149	NIL	149
Robertfulton	399	NIL	399
Seastreak	399	NIL	399
Total			1229

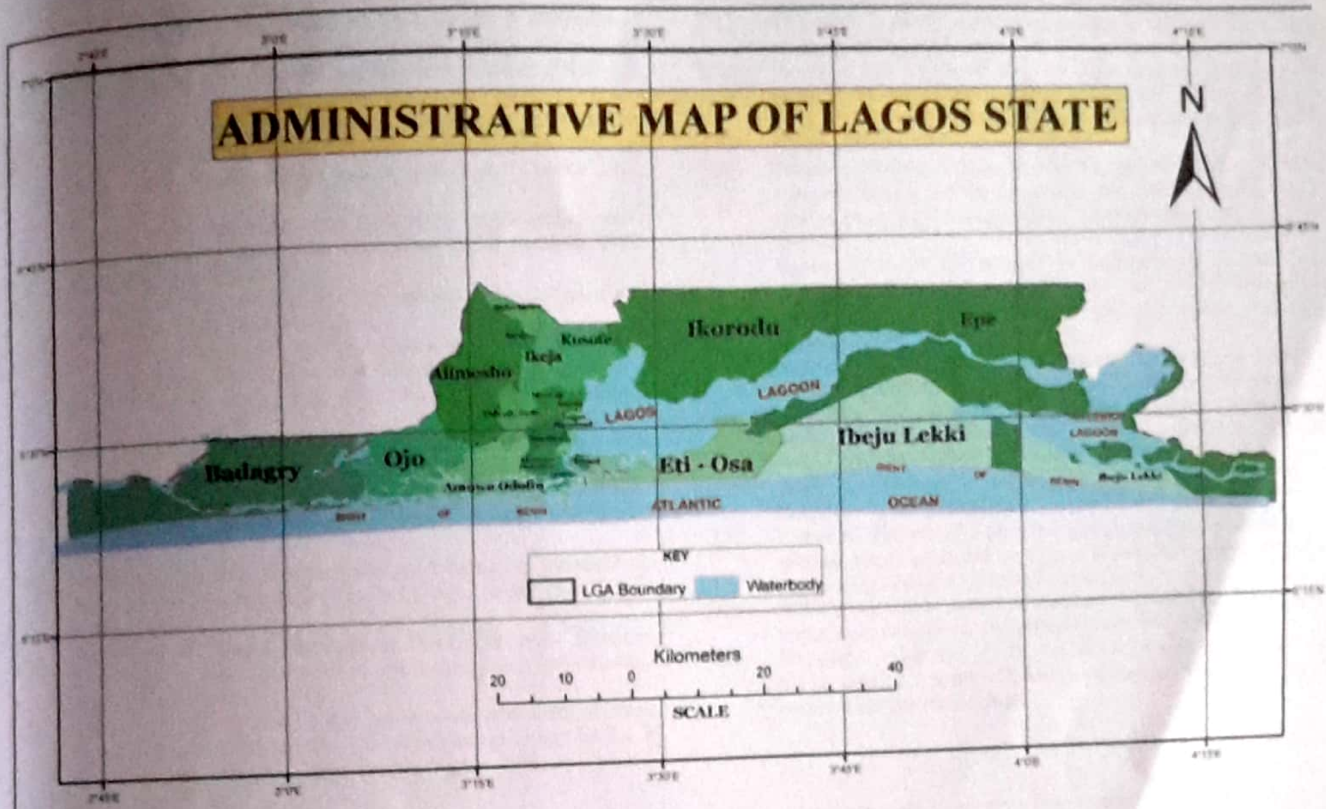

Fig. (8a). Map of the Study Areas showing water body in blue colour.

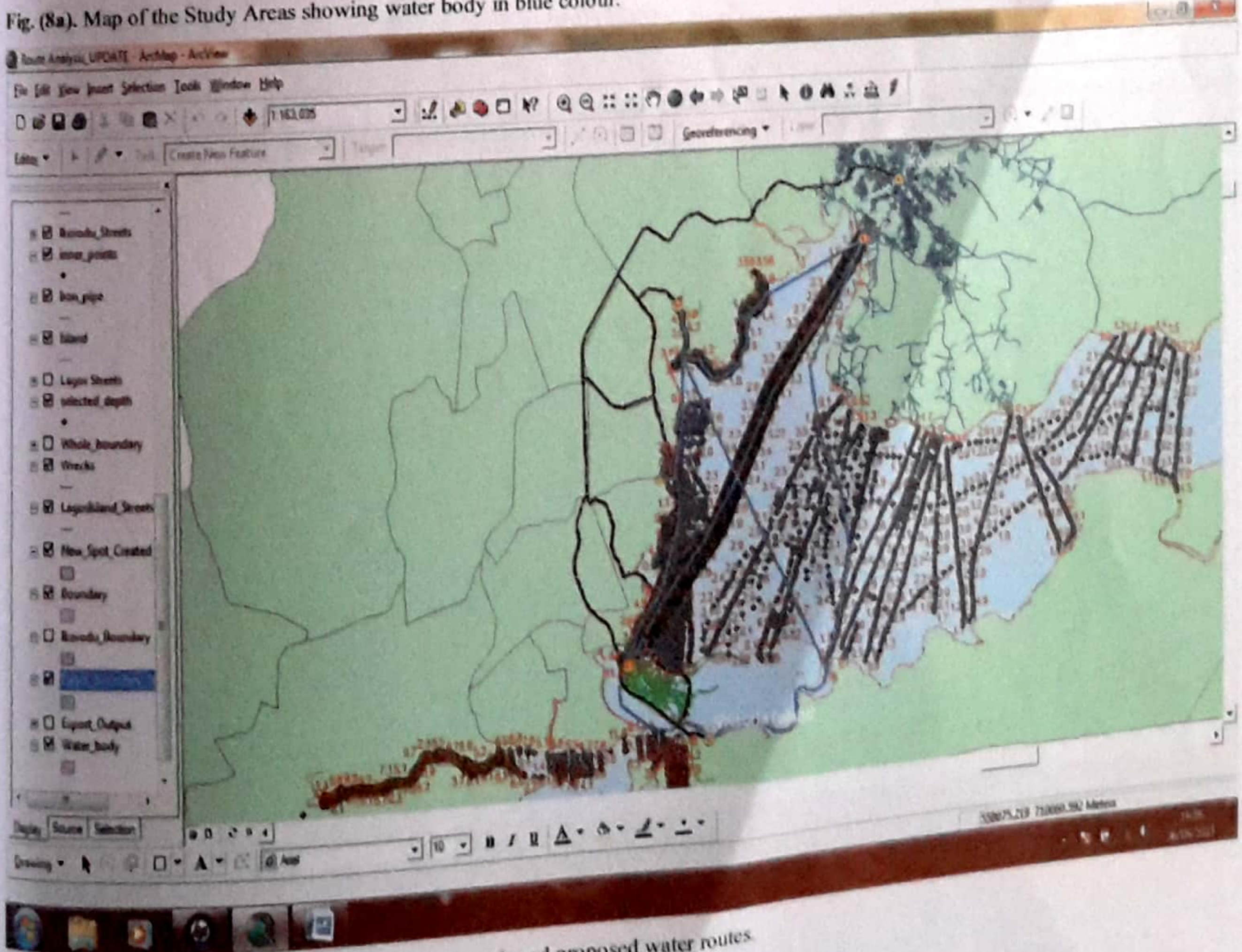

Fig. (8b). Water bed topography, existing road network and proposed water routes.

REFERENCES

[1] Adejare QA, Nwilo PC, Olusina JO, Opaluwa YD. A study of ferry service route network in Lagos Lagoon- Nigeria using graph theory. Journal of Geography and Regional Planning 2011; 4(6): 326-37.

[2] Al-Kaisy AF, Hall F, Reisman E. Developing passenger car equivalents for heavy vehicles on freeways during queue discharge flow. Transportation research part A: policy and practice 2002; 36(8): 725-42.

[3] Creating WP6 – Milestone report for M06.01, engine performance.

[4] Crozet Y. The prospects for inter-urban travel demand, JTRC Discussion Paper 2009-14.

[5] De Jong G, Van de Riet O. The driving forces of passenger transport. EJTRI 8 2008; (3): 227-50.

[6] Duranton G, Turner MA. The fundamental law of road congestion: evidence from US cities. American Economic Review 2010.

[7] IEA. Transport, energy, and CO2. Paris, France: International Energy Agency 2009.

[8] ITF. Transport outlook 2010.The potential for innovation. Paris, France: ITF 2010c.

[9] József Rohács, Gyozo Simongáti. The role of inland waterway navigation in a sustainable transport system. Transport 2007; 22(3): 148-53.

[10] Khisty CJ, Lall BK. Transportation engineering: an Introduction, Third Edition, Prentice-Hall of India Private Limited, New Delhi-110001, 2008.

[11] Mobereola D. Lagos Metropolitan Area Transport Authority LAMATA, a paper presented at the Lagos State Infrastructure forum, 18-19 November 2009.

[12] Ogunsanya AA. Monitoring and performance evaluation of Mass Transit Services." Urban Mass Transit in Nigeria. Edited by Tunji Bolade. Ibadan University Press, Ibadan, Nigeria 1989; pp. 115-31.

[13] Parry I, Small K. Should urban transit subsidies be reduced? American Economic Review 2009; 99(3): 700-24.

[14] Pickrell D. A desire named streetcar fantasy and fact in rail transit planning. JAPA 1992; 58(2): 158-76.

[15] Proost S, Van Dender K. Optimal urban transport pricing in the presence of congestion, economies of density, and costly public funds. Transportation Research Part A-Policy and Practice 2008; 42(9): 1220-30.

[16] Proost S, Delhaye E, Nijs W, Van Regemorter D. Will a radical transport pricing reform jeopardize the ambitious EU climate change objectives? Energy Policy (Special Issue) 2009; 37(10): 3863-71.

[17] Puentes R, Tomer A. The road . . . less travelled: an analysis of vehicle miles travelled trends in the U.S. Metropolitan infrastructure initiative series. Washington, DC: Brookings Institution 2008.

[18] Sjostedt Lars. A theoretical framework for analyzing issues of sustainable mobility. SAE International, Warrendale, PA 1994.

[19] Small KA, Verhoef E. Long-run trends in transport demand, fuel price elasticities, and implications of the oil outlook for transport policy, OECD/ITF JTRC Discussion Paper 2007b; pp. 07-16.

[20] Small KA, Verhoef E. Urban transport economics. New York: Routledge. Transport Mobility Leuven 2007.

[21] Taiwo K. The ase of Lagos: air quality improvement project. A seminar paper presented at Lagos Metropolitan Area Transport Authority (LAMATA), Lagos, Nigeria 2005.

[22] WB (1986): China Inland Waterways Project, The World Bank, http:// www.worldbank.org/transport/ports/iwt_dev.htm

[23] Winston C, Maheshri V. On the social desirability of urban rail transit systems. Journal of Urban Economics 2007; 62(2): 362-82, essays in honour of K. Small.

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