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Full Length Research Paper

A study of ferry service route network in Lagos Lagoon-Nigeria using graph theory

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Lagos State is endowed with international commerce, industry and infrastructure excellence drives. In Lagos State, traffic situation is chaotic and socio-economically unfriendly due to ills in multi-transportation modal functions. Urgent research and development attention is required to arrest total collapse of the entire modal system. In this study, a framework is developed for efficient utilization of Lagos waterway system as a complement to other transportation modes such as the dominating road mode. The paper has used passengers travel distances, travel times, travel delays and speed variations on road and water transportation systems in Lagos State to design a geographic information system (GIS) of waterway transportation system. This attempt has formed its base on graph theory, spatial interaction and urban transit capacity. The study has also designed a vector-based GIS for four (4) different spatial locations of the water transportation route network. Consequently, the water transportation at a peak hour commuter service that would complement existing bus, car and taxi in order to reduce the demand for road transportation in Lagos Metropolis was examined. From the study, water transport is found to have caused a reduced journey time by an average of 46.33%.

Key words: Traffic, graph theory, passenger travel distances, travel times, waterways.

INTRODUCTION

In transportation and logistics, development of a geographic information system (GIS) application allows study of route networks. Such an effort involves modeling and representation of routes network used by pedestrians and other modal users. It provides a means to characterize and quantify the barriers that may impede movement through the network, and serve as a tool to prepare individually tailored maps base on user-defined input. Characterizing route networks are fundamentals to GIS applications that deal with transportation (by air, land and sea), utility management (flow of water, gas or electricity), hydrology, and spatial interaction of tangible and non-tangible networks (Biale et al., 2006). In Lagos, mobility and accessibility that are provided to shape communities in trade, sociology and industrialization, have been hampered by transport system (Zuidgeest, 2005). By these, the study focuses on water transportation because the purpose is to facilitate proper use of water bodies in the area, encourage low-priced transportation and subsequently address long time neglect of travel by water. Using its interconnected Lagoons, Creeks, and Rivers, the Lagos coastal transportation system can be developed based on the existing dredged channels.

Traffic congestion is considered one of the main urban transportation problems with an estimated cost of about $100 billion annually in the US and comparable costs in other countries (Victoria Transport Policy Institute, 2005). Studies conducted by Shrank and Lomax (2001) placed the annual cost of traffic congestion at $2,805,000,000 in San-Francisco Bay Area in 1998 for 58,855,000 daily vehicles miles travelled with a negligible change in available lane miles. Traffic research still cannot fully predict conditions which “traffic jam” (as opposed to heavy, but smoothly flowing traffic) may suddenly occur (TTI, 2009). It has been found that individual incidents may cause ripple effects (a flowing failure) which then spread out and create a sustained traffic jam. Traffic congestion is not a sign of failure, but rather an inevitable by-product of vibrant, successful cities. Traffic congestion

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exists in every major metropolitan area in the world. Peak-hour traffic congestion in almost all large and growing metropolitan regions around the world may remain for some time. For instance, various authors, Oyesiku (2002), Adeniji (2000), Auclair (1999), World Bank (2001), Hook (1995), Coyle et al. (2000) and UNCHS (1998) asserted that travel speeds in cities are decreasing and the travel environment for pedestrians and people-powered vehicles are deteriorating in developing countries. Furthermore, inefficiency of the entire road transport system in five major cities with over 4 million people (Bucharest, Jakarta, Kinshasa, Lagos and Manila) in the sixteen developing countries experienced an average one-way journey to work of about one and quarter hours or more.

The economic and social waste from congestion necessitates the need that water transportation lives like a full time support to development of Lagos. Lagos is known not only as a centre of commerce and investment but also for severe traffic congestion problems. Transportation in Lagos State is usually chaotic. This is because six million passengers hustle daily between Lagos mainland and island. Motorized transportation accounts for more than 90% of passenger and freight traffic. With the enormous growth in car traffic in recent years, the increase in congestion is expected to continue in the years to come unless there is a commensurate road expansion or new ones constructed.

There are abundant water bodies that could be used but these are neglected and grossly unutilized. Insufficient information with respect to depths of the water bodies and desirable route for the boat perhaps inhibits aspiration and willingness for potential investor in water transport system. It is in view of this perennial oversight even by state governments with riverine areas that prompted this research.

Therefore this paper aimed at developing a framework for the efficient utilization of water transport system in Lagos lagoon as a complimentary mode to the road transport system. The objective of the paper is to evaluate water transportation as a peak-hour commuter mode that supplements existing road transportation offering and to estimate the average travel time (peak, off-peak) travel, distance, average passenger loads (peak, off-peak), vessels/ vehicle speed and capacity for water and road transport system. 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. In Lagos, there is an urgent need to complement travel demand on road to water as a congestion reduction strategy to free our roads from the evil of traffic jam.

METHODOLOGY

The study area is Lagos, with particular focus on Lagos Lagoon. Lagos is one of the African mega cities. It is located in south Western Nigeria on the west coast of Africa, within latitudes 6°23'N and 6° 41'N and longitudes 2° 42'E and 4° 00'E. Lagos State is flanged to the north and east by Ogun State, in the west by the Republic of Benin and to the south by the Atlantic Ocean/Gulf of Guinea. The total land mass of the state is about 3,475.1 km^2, which is just about 0.4% of the total land area of Nigeria. It is the physically smallest but second most highly populated state in the country with an estimated population of about 9 million inhabitants which is about 6.5% of the total population of Nigeria (Census, 2006). The metropolitan area accounted for the seventeen out of the twenty local government areas in Lagos State as shown in Figure 1. A considerable part of the state area is made up of Lagoon and creeks. Lagos Lagoon covers a total area of about 426.0 km^2 with a coastline and inland waterways; it reaches an average depth of about 1.6 m throughout the year with negligible or insignificant variations. On the west of the lagoon (south-west of the harbour) there are several creeks; these are the Lighthouse creek, Ologe lagoon, the Badagry creek, the main waterway leading to Badagry (Port Novo and Cotonou). Another creek joining the southern part of the main Lagos Lagoon to the Atlantic through Victoria Island is called Five Cowries creek. The North East of lagoon is bounded with Ikorodu local port that leads to Epe. Also at that region, there are several inlets from Ogun River, Majidun River and Agboyi creek. A sub-lagoon of the Lagos lagoon lies to the east of the harbour bound, and the bar beach between the Atlantic Ocean and the lagoon is called the Kuramo waters.

However, road transport currently plays a very important role in Lagos Metropolitan transport system. Water transport is also important and relevant in Lagos, because it cost less compared to the road transport system, therefore it requires less investment. A typical setting in Lagos is that the people live in Mainland and work in the Island. So far, 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 and rail transport. Therefore, this study employs graph theory in a vector based GIS to generate transport planning alternatives for different locations in Lagos State. This paper 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.

Other aspects of the study include the following stages:

1. Network design for ferry routes. These routes are; Lagos Central (Marina, Ebute Ero) to Ikorodu; Ikorodu to Agboyi (Oworonshoki); Lagos Central (Marina, Ebute Ero) to Agboyi (Oworonshoki); Ikorodu to Victoria Island; Agboyi (Oworonshoki) to Victoria Island; Victoria Island to Lagos Central (Marina, Ebute Ero) in Lagos using geographic information system
2. The estimation of travel times on water as well as on road. The travel time estimation was based on free flow traffic scenarios.
3. Evaluation of passenger carrying capacity on the water and road travel mode.
4. Adoption of 10 to100 km/h speed for analysis of travel mode.

The data used in this paper were collected between June 2006 and December 2010. Data were obtained from field survey using hydrographic survey techniques and hydrographic survey dataset were used to prepared navigation charts. The hydrographic survey

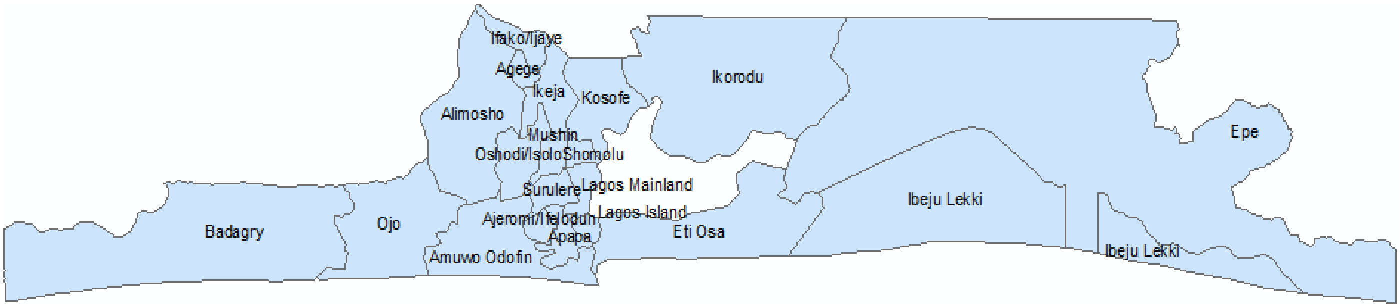

Figure 1. Map of the study area (Authors research, 2010).

data acquired were determined using echo sounder. Global positioning system was used to determine the planmetric coordinate of the sounding locations concurrently with the sounding exercise. Route analysis of water transportation system in Lagos lagoon was designed by connecting points of equal elevation (Figure 3). 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 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.

Model formulation

Many real-world situations can conveniently be described by means of a diagram consisting of a set of points together with lines joining certain pairs of these points. In such a diagram, we are mainly interested in whether or not two given points are joined by a line. The manner in which they are joined is immaterial. A mathematical abstraction of situations of this type gives rise to the concept of a graph. The formulation in this research work considers a connected network composed of a directed graph *G = {V, E}* with a finite number of nodes V connected by arcs E.

A graph is an ordered triple *(V(G), E(G), ψG)* 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 Equation (1) serves the purpose of clarification for this paper:

$$G = (V(G), E(G), \psi G), \quad (1)$$

where V(G) = {Lagos central(Marina, Ebute Ero,), Ikorodu, Oworonsoki (Agboyi) and Victoria Island} = {v_1, v_2 , v_3, v_4 }: E(G) = {e/e link between two locations: e_1, e_2, e_3, e_4, e_5,e_6}, and ψG is defined by; $\psi G(e_1) = v_1v_2$, $\psi G(e_2) = v_2v_4$, $\psi G(e_3) = v_2v_3$, $\psi G(e_4) = v_1v_3$, $\psi G(e_5) = v_3v_4$, $\psi G(e_6) = v_1v_4$

Estimation of link travel times

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

$$T = \sum T_t + \sum t_d \quad (2)$$

where T_t is travel time to traverse the link at cruise or congested speed (in minutes), and t_d is the travel time loss due to dwell time. Travel time is the actual time the passenger spends in the vehicle/ferry before reaching its destination. Several methods have been suggested (Black, 1981, Blunden and Black, 1984). According to Khisty and Lall (2008), a convectional Bureau of Public Roads (BPR) congestion delay function is often used. This traffic flow dependent travel time relationship is represented by the general polynomial function:

$$T_t = T_0\left[1+\alpha\left(\frac{Q}{Q_{\max}}\right)^{\beta}\right] \quad (3)$$

where T_t = travel time at traffic flow Q; T_0 = zero flow travel time; Q = traffic flow (vehicle/h); Q_{max} = practical capacity = $\frac{3}{4}$ * (saturation flow), and α & β = parameters.

Although passengers, especially in peak periods tend to optimize their spatial distribution for boarding, alighting, or travelling on transit vehicle, imbalances in these functions frequency occur, resulting in varying demands for space at different doors. Also, dwell time t_d, is the time required to serve passengers at the busiest door divided by the number of available doors, or channels (most fast ferry doors are dual stream, having two channels) plus the time required to open and close the doors. Similarly, dwell time according to Khisty and Lall (2008) can be computed using Equation (4):

$$t_d = P_a t_a + P_b t_b + t_{oc} \quad (4)$$

where 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), and t_o = door opening and closing time (s).

Link travel times on water route

In the absence of congestion, the travel time at cruise speed is simply the total link distance divided by the "zero-volume" cruise speed. Then in Lagos lagoon, a calibrated travel time relationship based on the general polynomial functions is developed given by Equation (5):

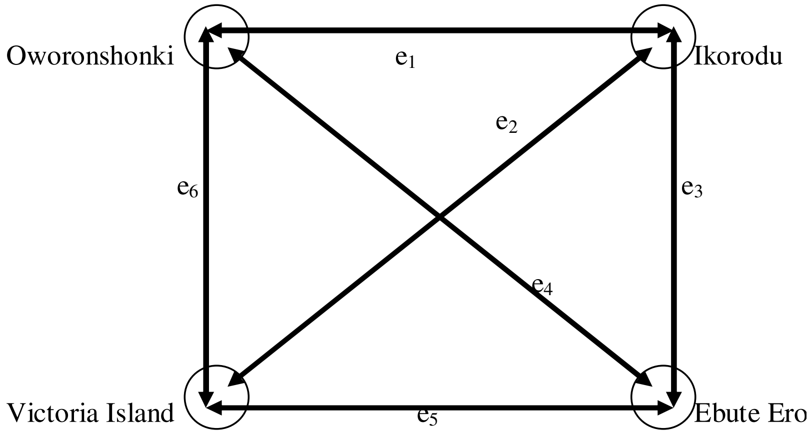

Figure 2. Reduction of a map (Figure 1) of a transport network to a graph.

$$T = \left[\frac{L}{S_p * 1.1} \right] * 60 + (P_a t_a + P_b t_b + t_{oc}) \quad (5)$$

where L = is the link length in kilometres; Sp = speed limit in kilometres per hour, and 60 = conversion factors from hours to minutes.

Link travel times on road route

In the previous study, the following factors were responsible for traffic congestion, indiscriminate parking of vehicles on the road, potholes, narrow road network, attitude of road user, urbanization, economic/population growth and presence of too many vehicles on the road. Based on the previously listed components, it is impossible for the vehicle to travel at free-flow speed and maximum speed varies from one traffic region to the other. Then in Lagos metropolis, a calibrated travel time relationship based on the general polynomial functions is developed given by Equation (6):

$$T = \left[\frac{L}{S_p * 1.1} \right] \left[1.0 + \left(\frac{v}{c} \right)^{7.0} \right] * 60 + (P_a t_a + P_b t_b + t_{oc}) \quad (6)$$

where L = is the link length in kilometres; Sp = speed limit in kilometres per hour; 60 = conversion factors from hours to minutes; v = link volume, and c = link capacity

While Equation (7) explained the maximum passenger-carrying capacity that can be carried past a given location during a given period of time, under specified operating condition, without unreasonable delay, hazard, or restriction, and with reasonable certainty (Khisty and Lall, 2008):

$$C_t = C_a + \alpha C_b \quad (7)$$

where C_t = total passenger capacity per vehicle; C_a = vehicle seating capacity, C_b = vehicle standing capacity, and α = fraction of C_b allowed.

Water route network design

In this paper, the composite map was used for selection of the proposed water transport system in the study. The design framework based on graph concept in Equation (1) is as shown in Figure 2.

RESULTS AND ANALYSIS

The results of the various numerical evaluations were discussed and the analysis of the results is presented here. Travel time estimation using Equation (5) for water mode of travel and equation (6) for road mode of travel were estimated for the ten (10) adopted speed strategies and results obtained for each route were as shown in Tables 2 to 7, respectively. The graphical representation of the results were as shown in Figures 4 to 9, while the water bed topography plotted from the bathymetric data for each route under consideration are depicted in Figure 3.

From the mathematical abstraction designed in Figure 2, the incidence and adjacency matrices for spatial interaction between the jetties were derived and Table 1 depicted travel distance matrix respectively.

The determination of the travel time for vessel/vehicle travelling from pickup node to delivery node under different speed scenarios was computed as follows;

1. Travel time (Victoria Island to Agboyi (Oworonshoki)): From the mathematical model using Equation (5) for water mode of travel and equation (6) for road mode of travel respectively the following travel time were obtained for the ten (10) practical speed given by Table 2 and Figure 4.
2. Travel time (Victoria Island to Ikorodu).
3. Travel time (Victoria Island to Ebute ero).
4. Travel time (Agboyi to Ikorodu).
5. Travel time (Agboyi to Ebute ero).
6. Travel time (Ikorodu to Ebute ero).

This paper considered the integration or combination of

Table 1. The spatial relationships between the jetties vis-à-vis the mode of travel.

Link ID	Pickup	Delivery	Road distance (km)	Water distance(km)
E_1	Victoria Island	Agboyi	21.610	20.307
E_2	Victoria Island	Ikorodu	36.789	23.195
E_3	Victoria Island	Ebute Ero	6.892	6.179
E_4	Agboyi	Ikorodu	17.068	13.654
E_5	Agboyi	Ebute Ero	15.065	14.306
E_6	Ikorodu	Ebute Ero	32.116	19.237

Table 2. The comparison of the road and water routes, travel speed and associated travel time between Victoria Island and Agboyi.

Speed km/h	Water distance (Km)	Road distance (Km)	Water travel time (Minutes)	Road travel time (Minutes)
10	20.307	21.61	110.7654545	235.7454545
20	20.307	21.61	55.38272727	117.8727273
30	20.307	21.61	36.92181818	78.58181818
40	20.307	21.61	27.69136364	58.93636364
50	20.307	21.61	22.15309091	47.14909091
60	20.307	21.61	18.46090909	39.29090909
70	20.307	21.61	15.82363636	33.67792208
80	20.307	21.61	13.84568182	29.46818182
90	20.307	21.61	12.30727273	26.19393939
100	20.307	21.61	11.07654545	23.57454545

Table 3. The comparison of the road and water routes in kilometres travel speed and associated travel between Victoria Island and Ikorodu.

Speed Km/h	Water distance (Km)	Road distance (Km)	Water travel time (Minutes)	Road travel time (Minutes)
10	23.195	36.789	126.5181818	401.3345455
20	23.195	36.789	63.25909091	200.6672727
30	23.195	36.789	42.17272727	133.7781818
40	23.195	36.789	31.62954545	100.3336364
50	23.195	36.789	25.30363636	80.26690909
60	23.195	36.789	21.08636364	66.88909091
70	23.195	36.789	18.07402597	57.33350649
80	23.195	36.789	15.81477273	50.16681818
90	23.195	36.789	14.05757576	44.59272727
100	23.195	36.789	12.65181818	40.13345455

high occupancy ferry services with bus services system with the intention of meeting the commuter travel demand. The number of passengers carried by bus/ferry in relation to the total capacity was measured in terms of the average number of passenger per operating bus/ferry per day using Equation (7). However, the survey carried out by LAMATA in June 2006 and 2010 on travel demand on the Third Mainland Bridge as well as Ikorodu road was used for the analysis of capacity of transit mode. From the two roads, buses of different classes with different number of passengers were considered and depicted in Tables 8 to 10.

In 2006, the total person flow is 10,062 in the peak hour. Cars, which represent 79% of the total vehicles, carry only 30.37% of the passengers; minibuses, which represent 16.09% of the total vehicles, carry 57.72% of the passengers; while, 'coaster and molue', which represent just 0.22 and 0.61% of the vehicles, carry 2.08 and 8.79%, respectively. Similarly, in 2010 the total person flow is 41,155; car which represents 64.82% of the total vehicles, carry only 13.63% of the passengers; minibuses, which represent 18.31% of the total vehicles,

Table 4. The comparison of road and water routes, travel speed and associated travel time between Victoria Island and Ebute ero.

Speed Km/h	Water distance (Km)	Road distance (Km)	Water travel time (Min)	Road travel time (Min)
10	6.179	6.892	33.70363636	75.18545455
20	6.179	6.892	16.85181818	37.59272727
30	6.179	6.892	11.23454545	25.06181818
40	6.179	6.892	8.425909091	18.79636364
50	6.179	6.892	6.740727273	15.03709091
60	6.179	6.892	5.617272727	12.53090909
70	6.179	6.892	4.814805195	10.74077922
80	6.179	6.892	4.212954545	9.398181818
90	6.179	6.892	3.744848485	8.353939394
100	6.179	6.892	3.370363636	7.518545455

Table 5. The comparison of the road and water routes, travel speed and associated travel time between Agboyi and Ikorodu.

Speed Km/h	Water distance (Km)	Road distance (Km)	Water travel time (Min)	Road travel time (Min)
10	13.654	17.068	74.47636364	186.1963636
20	13.654	17.068	37.23818182	93.09818182
30	13.654	17.068	24.82545455	62.06545455
40	13.654	17.068	18.61909091	46.54909091
50	13.654	17.068	14.89527273	37.23927273
60	13.654	17.068	12.41272727	31.03272727
70	13.654	17.068	10.63948052	26.59948052
80	13.654	17.068	9.309545455	23.27454545
90	13.654	17.068	8.275151515	20.68848485
100	13.654	17.068	7.447636364	18.61963636

Table 6. The comparison of the road and water routes, travel speed and associated travel time between Agboyi and Ebute ero.

Speed Km/h	Water distance (Km)	Road distance (Km)	Water travel time (Min)	Road travel time (Min)
10	14.306	15.065	78.03272727	164.3454545
20	14.306	15.065	39.01636364	82.17272727
30	14.306	15.065	26.01090909	54.78181818
40	14.306	15.065	19.50818182	41.08636364
50	14.306	15.065	15.60654545	32.86909091
60	14.306	15.065	13.00545455	27.39090909
70	14.306	15.065	11.14753247	23.47792208
80	14.306	15.065	9.754090909	20.54318182
90	14.306	15.065	8.67030303	18.26060606
100	14.306	15.065	7.803272727	16.43454545

carry 35.93% of the passengers, and coaster/molue, which represents 5.09% of the total vehicles carry 33.53% of the passengers. Also BRT/lagbus, which represent 2.26% of the total vehicles carry 14.55% of the passengers, while motorcycle, metroferry and canoe, which represent just 5.03, 0.07 and 0.14% of the vehicles, carries 0.88, 0.44 and 0.45% of the passengers, respectively.

In 2006, the total person flow is 18,024 in the peak hour. Cars, which represent 70.99% of the total vehicles, carry only 21.13% of the passengers; Minibuses, which represent 21.299% of the total vehicles, carry 59.16% of the passengers; while, coaster and molue, which represent just 0.20 and 1.54% of the vehicles, carry 1.44

Table 7. The comparison of the road and water routes, travel speed and associated travel time between Ikorodu and Ebute ero.

Speed Km/h	Water distance (Km)	Road distance (Km)	Water travel time (Min)	Road travel time (Min)
10	19.237	32.116	104.9290909	350.3563636
20	19.237	32.116	52.46454545	175.1781818
30	19.237	32.116	34.97636364	116.7854545
40	19.237	32.116	26.23227273	87.58909091
50	19.237	32.116	20.98581818	70.07127273
60	19.237	32.116	17.48818182	58.39272727
70	19.237	32.116	14.98987013	50.05090909
80	19.237	32.116	13.11613636	43.79454545
90	19.237	32.116	11.65878788	38.92848485
100	19.237	32.116	10.49290909	35.03563636

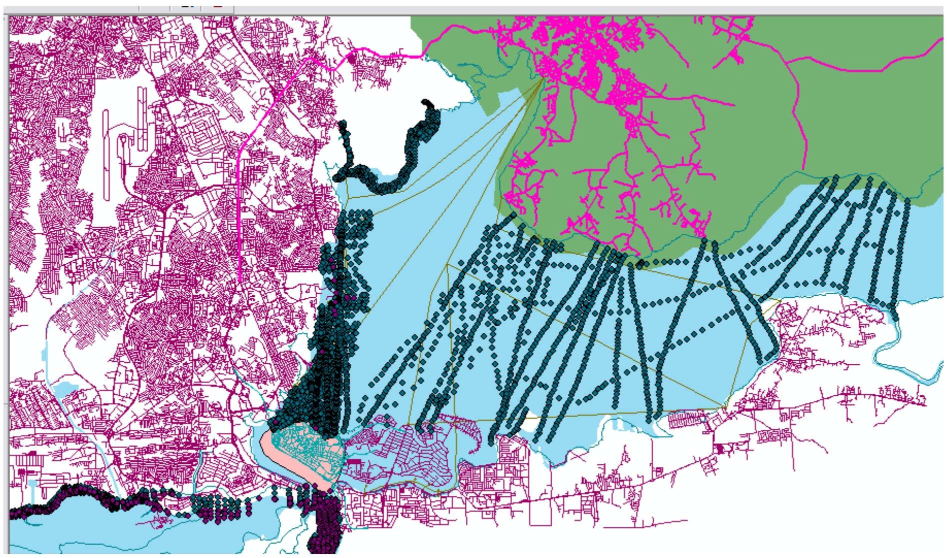

Figure 3. Water bed topography, existing road network and proposed water routes.

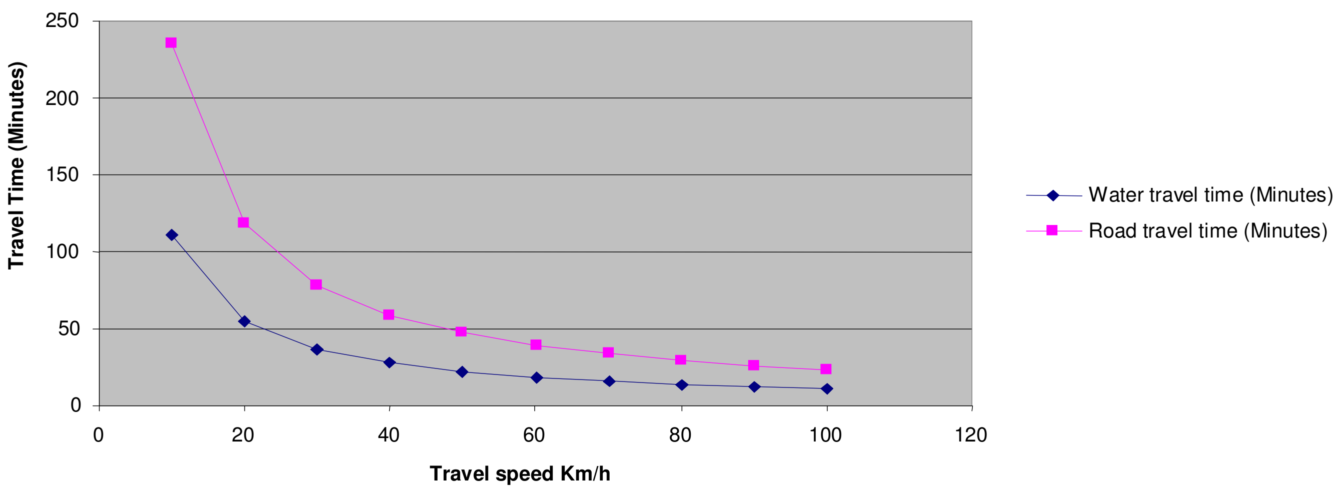

Figure 4. Water travel time at cruise speed, as well as road travel time due to congestion during the peak hours between Victoria Island and Agboyi.

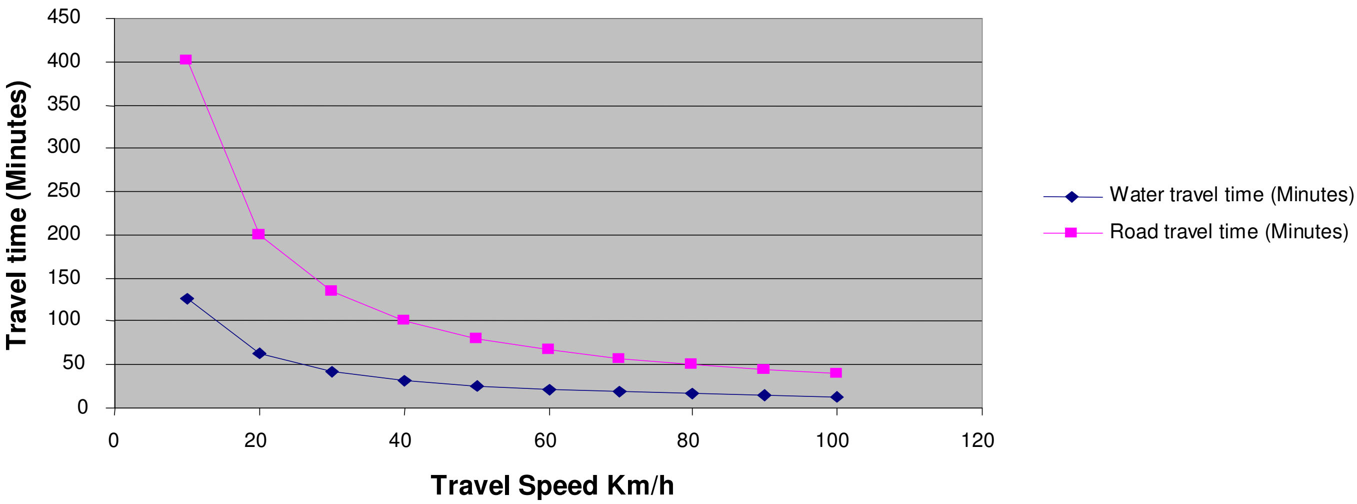

Figure 5. Water travel time at cruise speed, as well as road travel time due to congestion during the peak hours between Victoria Island and Ikorodu.

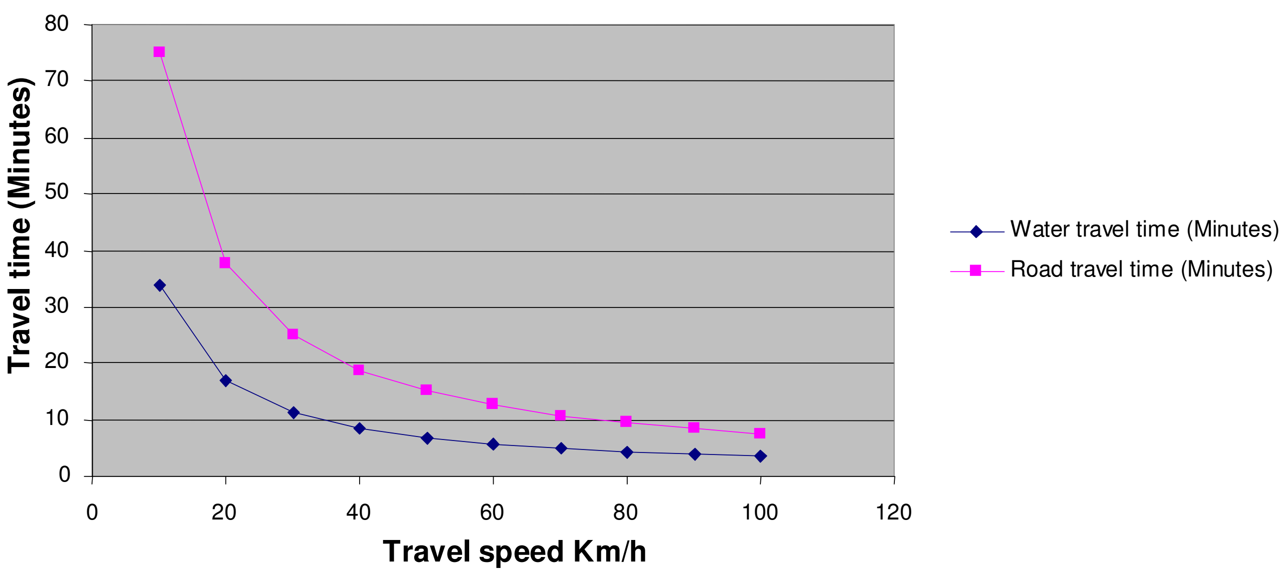

Figure 6. Water travel time at cruise speed, as well as road travel time due to congestion during the peak hours between Victoria Island and Ebute ero.

and 17.09%, respectively. Similarly, in 2010 the total person flow is 48,318; car which represents 56.53% of the total vehicles, carry only 18.32% of the passengers; minibuses, which represent 14.43% of the total vehicles, carry 43.66% of the passengers, and coaster/molue which represents 0.97% of the total vehicles carries 9.81% of the passengers. Also BRT/lagbus, which represent 2.07% of the total vehicles carry 20.57% of the passengers, while motorcycle, metroferry and canoe, which represent just 23.92, 0.04 and 0.08% of the vehicles, carries 6.46, 0.37 and 0.38% of the passengers, respectively.

Similarly, in comparison with the travel demand on the road, Table 10 shows existing ferry services on Lagos lagoon which includes passenger carrying capacity, travel time and number of trip per day.

From the results, in the absence of congestion, the travel time and travel distances on water are shorter than the road mode of travel; which accounted for the delay usually experienced on the road transport system in Lagos. 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. Similarly, in comparison with the travel demand on the road, water

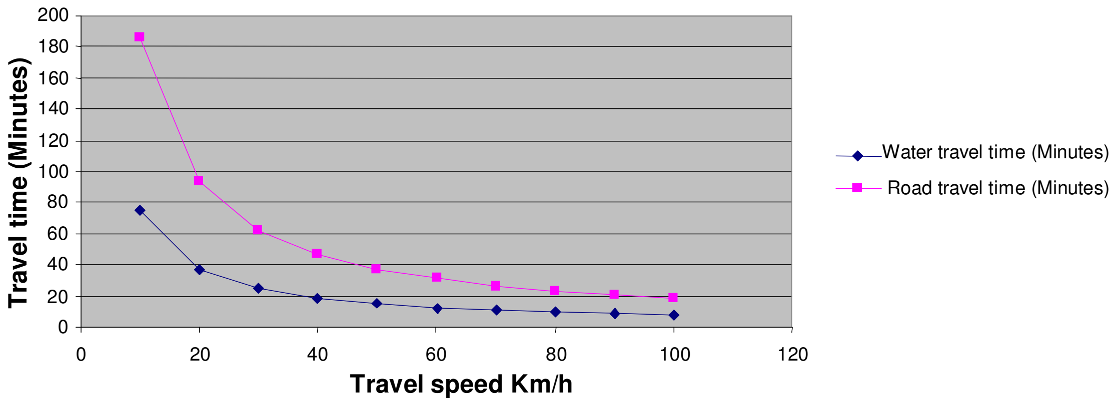

Figure 7. Water travel time at cruise speed, as well as road travel time due to congestion during the peak hours between Agboyi and Ikorodu.

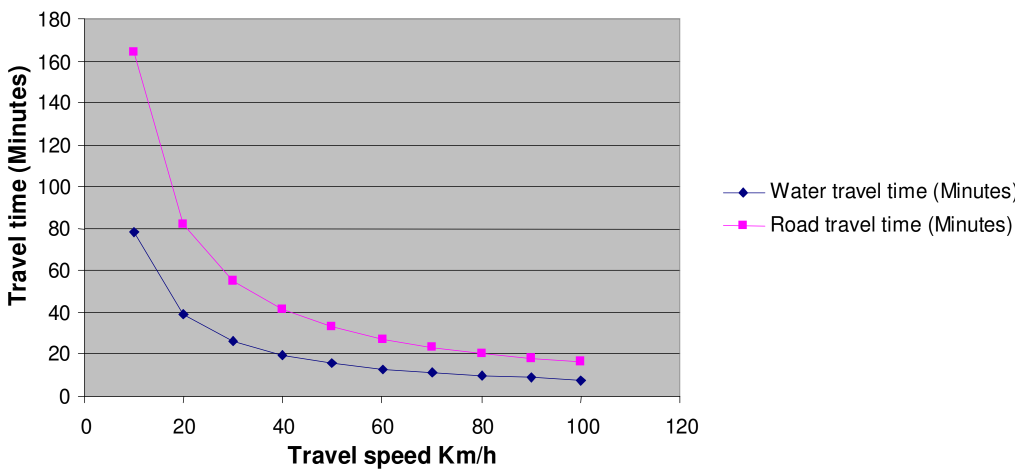

Figure 8. Water travel time at cruise speed, as well as road travel time due to congestion during the peak hours between Agboyi and Ebute ero.

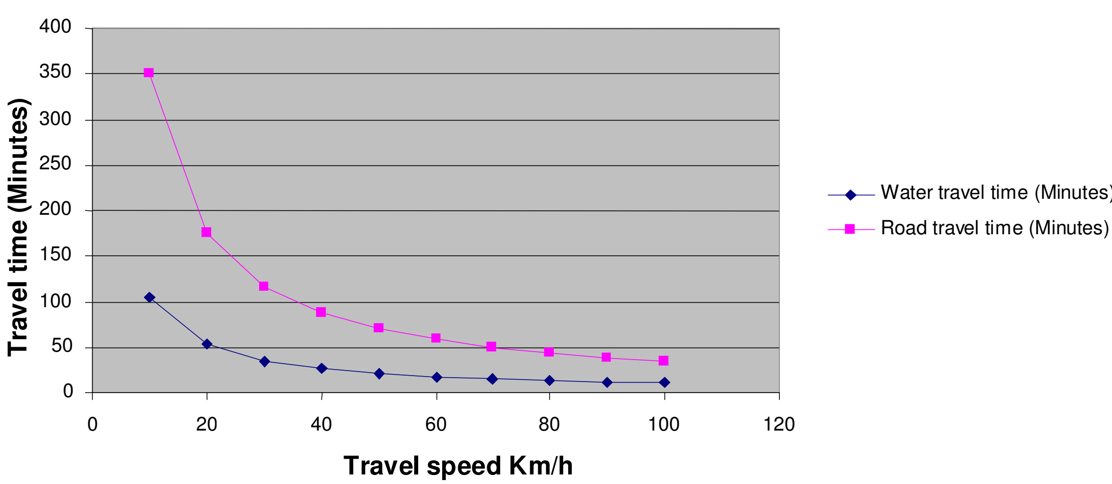

Figure 9. Water travel time at cruise speed, as well as road travel time due to congestion during the peak hours between Ikorodu and Ebute ero.

Table 8. Summary of vehicles and passengers travelling on Third Mainland Bridge based on traffic data for (2006, 2010) respectively.

2006	Vehicles/h	Persons/Vehicle	Persons/h	Percent of vehicles	Percent of persons
Mini buses	415	14	5807	16.09	57.72
Coaster	6	36	209	0.22	2.08
Molue	16	56	885	0.61	8.79
Car	2037	1.5	3056	79.00	30.37
Truck	105	1	105	4.08	1.05
Total	2579		10062	100.00	100
2010					
Minibus	1056	14	14786	18.31	35.93
Coaster/molue	294	47	13799	5.09	33.53
Car	3738	1.5	5608	64.82	13.63
Heavy	247	1	247	4.28	0.60
BRT/lagbus	130	46	5988	2.26	14.55
Motorcycle	290	1.25	363	5.03	0.88
Metro ferry	4	45	180	0.07	0.44
Speed boat	8	23	184	0.14	0.45
Total	5768		41155	100.00	100

Table 9. Summary of vehicles and passengers travelling on Ikorodu Road based on traffic data for (2006, 2010) respectively.

2006	Vehicles/h	Persons/Vehicle	Persons/h	Percent of vehicles	Percent of persons
Mini buses	762	14	10662	21.29	59.16
Coaster	7	36	259	0.20	1.44
Molue	55	56	3080	1.54	17.09
Car	2539	1.5	3809	70.99	21.13
Truck	214	1	214	5.98	1.19
Total	3577		18024	100.00	100.00
2010					
Minibus	1507	14	21093	14.43	43.66
Coaster/molue	101	47	4741	0.97	9.81
Car	5902	1.5	8853	56.53	18.32
Heavy	206	1	206	1.97	0.43
BRT/lagbus	216	46	9939	2.07	20.57
Motorcycle	2497	1.25	3122	23.92	6.46
Metro ferry	4	45	180	0.04	0.37
Speed boat	8	23	184	0.08	0.38
Total	10441		48318	100.00	100.00

travel mode would provide significant savings in travel time as shown in Table 12 due to increased speed and reduced delays because of no congestion problems; it would reduce the vehicle operating cost due to reduction in congestion on the existing roads and reduced the physical and mental stress in car driving.

It is obvious that traffic density and frequency are unevenly distributed in Lagos State. However, certain time periods are intuitively considered to command heavier traffic than others. Such temporal variations are caused mainly by the distribution of opening and closing work hours and other economic activities. As at present, this heavy traffic is more pronounced on the three bridges (Third Mainland, Eko and Carter) as well as Ikorodu road because they serve as major throughways and routes to high spot of intense commercial activities on Lagos

Table 10. Observed travel time from the existing metro ferry services.

Existing ferry name	Travel time (Minutes)	Passenger carrying capacity	cost (naira) per passenger	Total trip per day	Route name
Metro ferry	40	45	300	8 trip per day	Ikorodu to Ebute Ero
Speed boat	20	23	350	8 trip per day	Ikorodu to CMS
Speed boat	30	23	500	8 trip per day	Ikorodu to Victoria Island

Source: Author's field survey (2010).

Table 11. 12 h traffic count on selected roads in metropolitan Lagos.

S/N	Road	No. of vehicles in both direction (12 h traffic counts)	No. of vehicles in both direction P/h
1	Third Mainland Bridge	220,190	18,349
2	Carter Bridge	50,962	4,247
3	Eko Bridge	150,130	12,511
4	Western Avenue	110,190	9,183
5	Murtala Mohammed Way	21,302	1,775
6	Herbert Macauley Way	88,345	7,362
7	Ojuelegba- Mushin	56,345	4,695
8	Ikorodu Road	300,238	25,020
9	Agege Motor Road	60,123	5,010

Sources: LAMATA, (2008) and Author's field survey (2008).

Table 12. A prototype commuter ferry total travel time on the routes (Authors research, 2010).

Link ID.	Pickup	Delivery	Speed of travel (m/s)	Water distance (Km)	Vessel draught	On water travel time (Min)	Loading and unloading time (Min)	Total travel time
e_1	Victoria Island	Agboyi	14.42	20.307	1.2	23	15	38
e_2	Victoria Island	Ikorodu	14.42	23.195	1.2	27	15	42
e_3	Victoria Island	Ebute Ero	14.42	6.179	1.2	7	15	22
e_4	Agboyi	Ikorodu	14.42	13.654	1.2	16	15	31
e_5	Agboyi	Ebute Ero	14.42	14.306	1.2	17	15	32
e_6	Ikorodu	Ebute Ero	14.42	19.237	1.2	22	15	37

Central, Lagos Island, Victoria Island and Ikoyi. 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 11. These routes are directly linked to all the identified industrial areas and CBD zones.

Passenger service is an important factor to be considered during the transportation planning. The factors usually considered in the passenger service quality for a transportation system includes time taken for the service, comfort, entertainment and safety. Here, only the "service time" that is, the time taken by the transporters to serve their passenger is considered as passenger service quality to compare the transportation modes. The other factors for the service quality were excluded as it was a short distance travel. In this work, the trip time was taken as the service time. The ratio of this service time of water transport to the road transport was taken as the passenger service index given in Table 13. While 50 km/h speed was adopted for the two mode of travel for the routes under consideration in this study.

Conclusion

The paper has used travel to evaluate use of passenger ferry on the Lagos Lagoon as a peak-hour commuter mode. Also, the study has evolved mathematical model in a vector based GIS environment to generate an

Table 13. Passenger Service Index, $I_s = \frac{(triptime)_{water}}{(triptime)_{road}}$.

Water travel time (min)	Road travel time (min)	Passenger service index (I_s)
20.3070	37.3260	0.5440
23.1950	63.5440	0.3650
6.1790	11.9042	0.5191
13.6540	29.4808	0.4631
14.3060	26.0211	0.5498
19.2370	55.4725	0.3468

enhanced transport planning alternatives for four (4) different spatial locations. The work has also evaluated travel times and travel carrying capacity on the road and water transportation system and developed a water routes network (WRN) for the proposed ferry services in Lagos metropolis. In light of the pressing need to move people and goods with the least possible energy expenditure, the study has settled for water and rail transport as a natural choice for movement.

However, the paper also concludes that investment in the water transport system could unlock a host of energy and cost savings as well act as a sustainable solution to our infrastructural needs. The study also settled that Barges that are an intriguing transport option form a sustainability point of water research view. From the study, also, it is confirmed that any form of infrastructure construction, especially transportation routing has traditionally been associated with "destruction of nature" and has had a bad public image. This method agreed in this paper has acknowledged the need for improving transportation infrastructure without unnecessary environmental damage. Water transportation can assist in the reduction of road congestion and thus increase the life span of the roads. From the analysis, water transport is found to have caused a reduced journey time by an average of 46.33%.

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