Developing Bimodal Choice Functions for Lagos Urban Transportation System using Hybrid Technique

Q. A. Adejare[1], J. O. Olusina[2], J. B. Olaleye[2]
[1]Department of Surveying and Geo-informatics, Faculty of Environmental Technology, Bells University of Technology
[2]Department of Surveying and Geo-informatics, Faculty of Engineering, University of Lagos
Corresponding author email address: quadriadejare@yahoo.com; seidelgeo@gmail.com

Abstract
Lagos Metropolis has been known for traffic congestion over the years. This chaotic traffic system brings about financial and man-hour losses. The situation requires the introduction of alternative modes of transportation such as the waterway. However, no adequate research attention has been given to the system. Therefore, this study investigates the parameters that influence commuters' preferences for the bimodal transportation options. The identified parameters based on literature are integrated using fuzzy logic, logistic regression and bathymetric information in order to address the modal-choice complexity and navigability through the waterways. In addition, survey-based data has been utilized to assess the socioeconomic characteristics of littoral residents from Ikorodu Town to Lagos Island. Data acquired was supplied into the binary logit model from, which the probability of modal choice preference was determined. Results show that travel time, travel cost, vehicle capacity, traffic safety and income influence the choice of commuters in Lagos Metropolis. The significance of these five parameters was determined at 95 % confidence interval. Increase in cumulative cost of travel leads to decrease in probability of the modal choice. Furthermore, the use of high capacity ferry services coupled with reduced travel cost on waterway leads to reduction in commuters plying the roads; hence, resulting in considerable reduction of traffic congestion in Lagos Metropolis.

Keywords: *Commuter, fuzzy logic, regression, traffic, waterway*

1.0 INTRODUCTION

The effects of traffic congestion on commuters include; increases travel time, travel cost and physical and psychological discomfort (Taylor, 2002). Traffic congestion is considered one of the main urban transportation problems with an estimated annual cost of approximately US $120 billion in the US and comparable costs in other countries (VTPI, 2017). The city of Lagos in Nigeria with a road network of 2600 km, is a renowned world fast growing city that has over the years been experiencing problem of road traffic congestion. This problem has consequently rendered the city almost immobile over time and space. The roads in this city are frequently congested with over 222 vehicles per km (Taiwo, 2005; Odeleye and Oni, 2007; Adejare *et al.,* 2011; Olagunju, 2015) against 11 vehicles per km Roadway Level of Service (LOS) for a category A (TRB, 2000). Road traffic congestion in Lagos Metropolis is characterized by slower speeds, longer transit travel time, and increased queuing. Similarly, road transportation infrastructure in Lagos is failing to keep up with the city's rapid population growth and development (Edelman, 2015).

Demographically, the density of Lagos is much higher than other cities in Nigeria. The total land mass of Lagos State is about 3,577.28 km^2, which is just 0.4 % of the total land area of Nigeria. It is physically the smallest but the second most highly populated State in the country with an estimated population of over 9 million, which is roughly 6.5 % of the total population of Nigeria (Census, 2006). Nigeria's population density is estimated to be 100 persons per km^2, but that of Lagos is 1000 persons per 0.4km^2 (LAMATA, 2014) with annual population growth rate of 5.0 to 5.5 % (Somuyiwa, 2010; Olagunju, 2015).

In terms of transportation, Lagos State is naturally endowed with navigable creeks: Lighthouse creek, Badagry creek, Five Cowries creek, Agboyi creek and lagoons Ologe Lagoon, Lagos Lagoon, Kuramo water and Lekki Lagoon) that are suitable for urban transit services (Adejare *et al.,* 2011). It also has 26 km rail line that links the commercial Southern part of the city with the residential settlement of the Northern part of Lagos State. As a result, Lagos State has the potential of benefiting from a seamless multi-modal transportation system. Ironically, road transport accounts for more than 90 percent of all intra-urban movement (Oni, 2004). Furthermore, due to road side development and land use activities (urban furniture, fly over), it becomes almost impossible to further widening the road network to increase the roadway capacity.

LAMATA (2014) highlighted positive steps in dealing with traffic congestion as contained in their 30-years transportation improvement plan. Essentially, the steps include light rail schemes and Bus Rapid Transit (BRT) services in Lagos State. However, according to Edelman (2015) given the existing land use structure of Lagos, the integration of light rail schemes and BRT buses is not likely to ameliorate the problems of traffic congestion. Edelman (2015) suggested a system, which will include non-land based systems as a more assuring way to solve the problem. Moreover, inland waterways sector has always been neglected to the detriment of the navigable rivers in Lagos State and the riverine dwellers (Asenime, 2008; Adejare *et al.,* 2011). However, sufficient information on feasible routes based on bathymetry data are lacking. The data bank is in poverty of data on the characteristics of water bodies, their positions and routing that could ease boat movement and ease potential investment in water transportation system. The current ferry system in Lagos is lacking in size and accessibility and therefore unable to offer the required attraction of commuters. Waterway transportation system is not fully utilized in Lagos metropolis.

It is in view of these and the need to address the ills that this research is prompted. However, well-developed water transportation can assist in the reduction of road congestion and thus increase the life span of the roads. Therefore, inland waterway services using Lagos Lagoon to travel from Ikorodu town to Lagos Island and vice versa can be a complementary and effective modal choice that could minimize travel demand on the existing roadway. Ikorodu town falls under residential land use classification while Lagos Island is a mixed of commercial and residential (Oni, 2004). This route as indicated in **Figure 1** is an active transportation corridor that received substantial daily traffic flow couple with Edelman (2015) assertion that there is need for non-land based transportation as a sustainable solution to traffic congestion in Lagos Metropolis. Waterway can provide a good alternative to compensate for the delay experienced on the roadway due to flexibility of waterway travel mode and empirically determined bathymetry data along the study route. This paper proposed an integration of probable and possible modal choice model to find, which variables strongly influence commuters' choice along these corridors in Lagos State.

2.0 METHODOLOGY

2.1 Conceptual Framework

Development of a descriptive travel behaviour model is one of the most essential tasks for transport planners to formulate sustainable transportation policies. Moreover, infrastructural facilities for commuters should cater for both the present and future needs. In such cases, the transport models have to replicate observed conditions closely so that the evolved transport policies can be effectively and efficiently implemented to yield maximum benefits (Sarada *et al*., 2014). A number of modal split models have been developed that estimate the probability of modal patronage given knowledge of the generalized costs of travel for competing modes. From previous studies, three types of mathematical concepts have been used to construct stochastic modal choice functions for individual behaviour and these are: discriminant analysis, probit analysis and logit analysis (Talvitie, 1972; Sarkar *et al.,* 2014).

Akiyama and Mizutani (2001) proposed soft computing model such as Fuzzy Logic, Neural Network, and Fuzzy Neuro in order to described various aspect of travel behaviour. The utility function in the fuzzy logit model is described using fuzzy reasoning instead of using mathematical function such as linear function in order to reflect human decision with vagueness, subjectivity, imprecision and ambiguity into discrete choice models. According to Sarkar *et al.* (2014) irrespective of the method used, the fundamental objective is to find a linear combination of explanatory variables, such as Eq. 1, in order to evaluate modal split travel behaviour more precisely.

$$U(i) = V(i) + e(i) \quad (1)$$

where: $U(\mathrm{i})$ is the choice function for the alternative *i,* $V(i)$ is the deterministic function of the attributes of (*i*) and $\mathrm{e}(i)$ is a stochastic component, a random variable that follow Gumbel distribution (Mizutani and Akiyama, 2001; Transportation Planning Handbook, 2009; Sarada *et al.,* 2014 and Sarkar *et al.,* 2014). Therefore, utility function could be derived using a linear combination of variables as shown in Eq. 2.

$$U = \beta_o + \beta_1 x_1 + \beta_2 x_2 + ... + \beta_m x_m \quad (2)$$

where: U is the utility associated with the choice of a transport mode; β_o is a constant; $x_i \ldots x_m$ are the independent variables; $\beta_i \ldots \beta_m$ are the slopes of the effect variables on the independent variables.

Also, it may be said that the individual passenger (*n*) will select an alternative (*i*) if the perceived U(*i*) of alternative (*i*) yields maximum benefit. According to De Jong and Riet (2008), there are three main drivers of modal choice for passengers namely: income levels, relative user costs (including time costs), and public policy. Reviews of relevant literature (Sarkar *et al.,* 2014; Sarada, 2014) show that travel time and travel cost are the major influencing attributes for the travel modal choice. Moreover, travel cost has been established to consist of tangible (e.g. travel fare) and intangible (e.g. traffic safety, comfort, aesthetic and congestion). In addition, information about intangible travel cost determination in modal split model particularly with respect to passenger's perception is always subjective in nature. Passenger's intangible travel cost is always stated in linguistic terms (e.g. very weak, weak, medium, strong, and very strong). The question is how "strong" is the intangible cost? Or how "weak" is the intangible cost or what is the average cost perception? Therefore, it is necessary to transform and evaluate these linguistic ratings to more appreciable and precise numerical equivalent for analysis. Furthermore, Abdel-Aty *et al.* (1994) adopted advanced binary Logit model to estimate respondents' choice to accept or reject an Advance Traffic Information System (ATIS) advice. General expression of Logit model is stated in Eq. 3.

$$P_i = \frac{\mathrm{e}^{U_i}}{\sum_{j=1}^{m} e^{U_j}} \quad (3)$$

where: P_i is the choice probability of route *i*; U is the utility associated with the modal choice.

The utility function could be derived using a linear combination of variables as shown in Eq. 2. Equation (3) seeks to determine the proportion of trip that will select a specific mode, waterway (*i*), which involves the exponential transformation of the utilities. The proportion of trips that will be attracted by each mode is then determined by Eq.4 as follows (Sarkar *et al.,* 2014):

$$P_i = \frac{U_i}{\sum_{j=1}^{m} U_j} = \frac{\beta_o + \beta_1 x_1 + \beta_2 x_2 + ... + \beta_m x_m}{\sum_{j=1}^{m} \beta_o + \beta_1 x_1 + \beta_2 x_2 + ... + \beta_m x_m} \quad (4)$$

where: U_i is the utility of mode *i* (waterway), U_j is the utility of competing or alternative modes *j* (roadway); β_o is a constant; $x_i \dots x_m$ are the independent variables; $\beta_i \dots \beta_m$ are the coefficient of explanation; P_i is the probability of choosing waterway mode (*i*).

In this study, only two competing modes are involved and Eq. 5 is appropriate for this analysis (Sarada *et al.,* 2014 and Talvitie, 1972).

$$P_i = \frac{e^{U_i}}{1 + e^{U_i}} \quad (5)$$

In the binomial sense of statistical reasoning, if the probability of choosing mode *i* waterway is as given in Eq. 5; then the probability of choosing the other competing mode *j* is:

$$P_j = 1 - P_i = \frac{1 + e^{U_i}}{1 + e^{U_i}} - \frac{e^{U_i}}{1 + e^{U_i}} = \frac{1}{1 + e^{U_i}} \quad (6)$$

Equations (5 and 6) are non-linear as they contain exponential functions. In order to use a linear logit model to make predictions on the travel behaviour of commuters, the non-linear logit model has to be transformed to a linear logit model. The transformation behaves in the following pattern (Sarada *et al.,* 2014; Sarkar *et al.,* 2014 and Talvitie, 1972):

$$\left(\frac{\boldsymbol{P_i}}{\boldsymbol{P_j}}\right) = \boldsymbol{e}^{\beta_o + \sum_{k=1}^{m} \beta_m x_m} \qquad y = e^x \text{ then } x = \log_e y. \quad (7)$$

As logit model is simply a log ratio of the probability of selecting a mode to the probability of not selecting that mode, it can also be expressed as Eq. 8.

$$\log_e \left(\frac{P_i}{P_j}\right) = U_k = \beta_o + \sum_{k=1}^{m} \beta_m x_m \quad (8)$$

Therefore, Eq. 8 is known as logit model, which was adapted to predict choice probability of occurrence of an event. The concept of this logistic function can be described from the explanation of logistic function whose probability always ranges between 0 and 1 (logit curves). The overall structure is a logit model. The utility function in this logit model is a fuzzy logit-based reasoning concept in order to reflect ambiguous human decision into discrete choice models. Hence, the following variables; Total Travel time (x_1), Travel fare (x_2), Capacity (x_3), Income of commuters (x_4), Educational level (x_5), Occupation (x_6), Purpose of the journey (x_7), Gender (x_8), Age (x_9), Aesthetic (x_{10}), Comfort (x_{11}) and Traffic safety (x_{12}) were sourced from literature and used in this study.

2.2 Modelling

The data used for the model was obtained through random sampling social survey among littoral resident. Moreover, twelve parameters were collected from social survey conducted on littoral residents who frequently use these routes in 2015. The respondents were asked about their socioeconomic characteristics, current traveling route, their choice of mode and choice of route. Travel time by road vehicles is derived based on in-vehicle travel time survey conducted along the study routes with prevailing vehicle operating speed of 25 $kmhr^{-1}$ in 2014-2015. While an average operating speed of 35 $kmhr^{-1}$ was observed for waterway ferry. The total sample consists of 2558 respondents. In the survey, passenger preferences for modal choice for two modes of travel from Ikorodu Town to Lagos Island were questioned from the littoral residents.

Transportation passengers' perceptions for choice of travel were inquired. With the help of questions and grades, road transportation and water transportation users' evaluation for three road routes and two water routes were displayed **Figure 1**. Transportation passengers' perceptions about intangible travel cost for modes of travel were displayed by grade (numerical rating). The boundaries of grades are selected as 0 – 25 (Olusina *et al.,* 2010; Sadi-Nezhad *et al.,* 2011; Hamid-Mosaku, 2014) for all the parameters. The grades were accounted for using the earlier stated five fuzzy linguistic terms. In fuzzy logic model, membership functions of input and output parameters are determined based on survey results or expert knowledge, and/or a combination of the two. In this work, triangular fuzzy number was used to transform intangible transportation cost ratings to precise values used in commuters' utility analysis as indicated in **Figures 2a and 2b**.

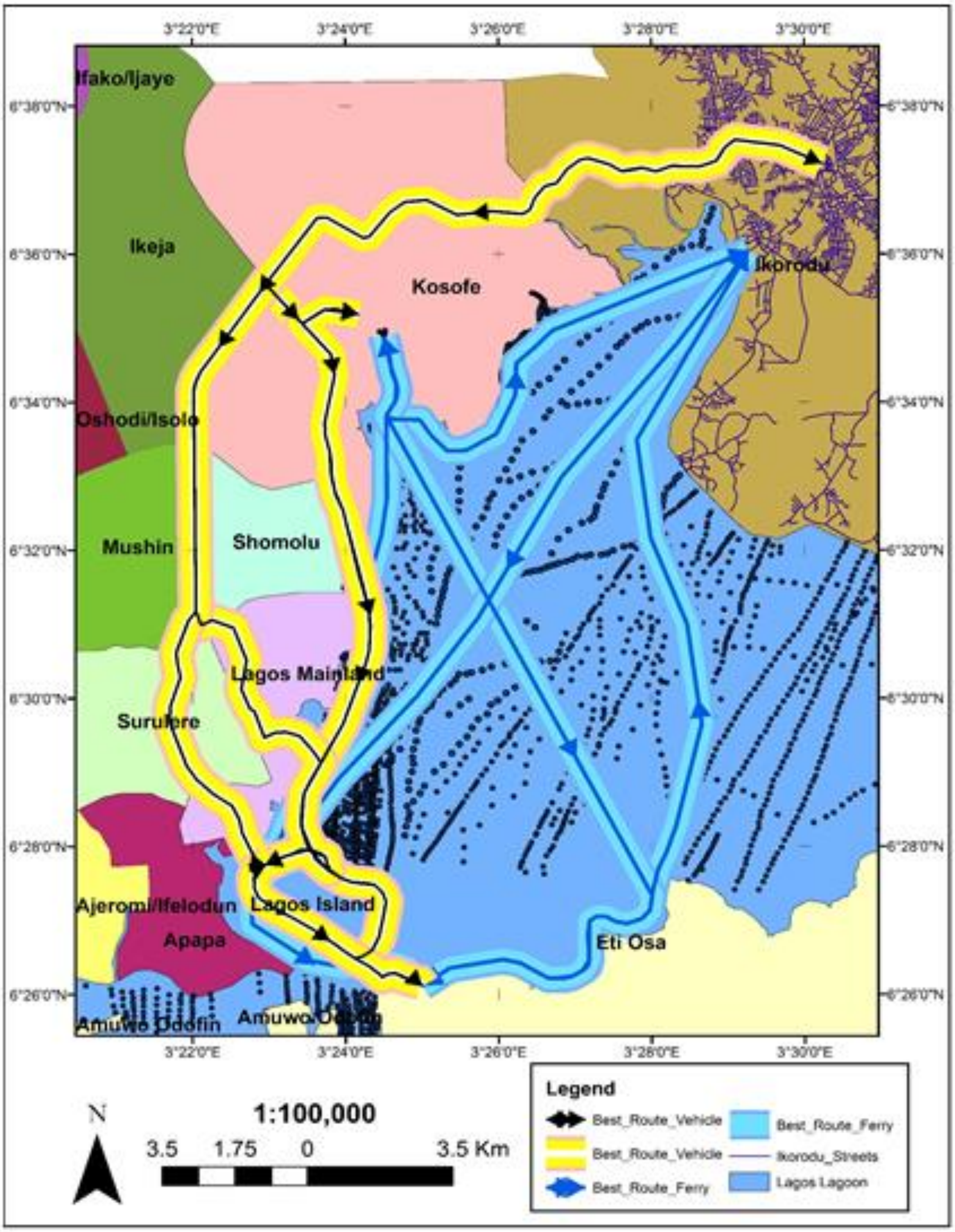

Figure 1: **Lagos Lagoon bed topography, Existing Road Network (Yellow) and Proposed Waterway Routes (Blue)**

Furthermore, **Figure 1** shows the proposed transportation network to ease traffic congestion on Lagos Metropolis. From interview with current boat operators, the existing navigable routes were based on driver experiences and not scientific. Appropriate navigable route was determined based on bathymetry data and detailed examination of the navigation charts within Lagos Lagoon.

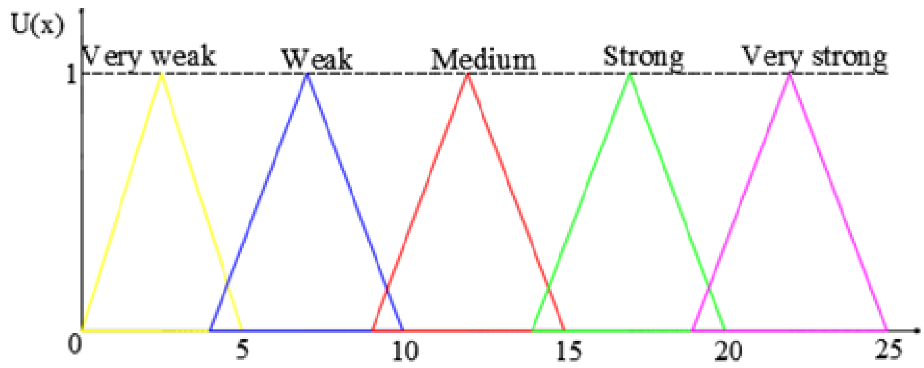

Figure 2a: Triangular membership function

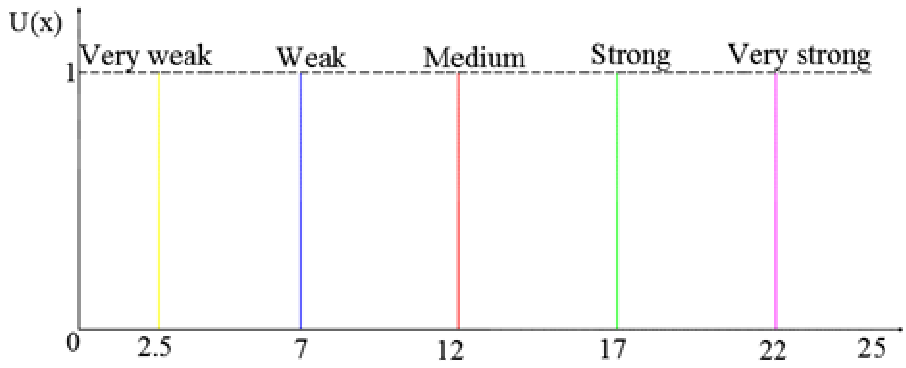

Figure 2b: Derived Triangular Fuzzy Number

Figure 2a was reduced to singular value for each triangle: very weak = 2.5, weak = 7, medium =12, strong = 17 and very strong =22. From **Figure 2b** derived triangular fuzzy number were used for aesthetic, comfort and traffic safety parameters in binary logistic regression analysis. Furthermore, the Bathymetry survey was carried out using South SDE-28 Echo sounder, DGPS receiver and Hypack 2008 Hydrographic Software from 2011-2015. The raw data acquired by the South SDE-28 Echo sounder was sorted by Power Nav software. The sorted data were then further processed using Hypack 2008 software to determine waterway navigable routes as indicated in **Figure 1.** Therefore, tangible cost was computed using known algorithm while intangible cost was computed using fuzzy adjectives based on literature.

3.0 RESULTS AND DISCUSSION

The variables used for the calibration of the passengers' model choice as discussed in Section 2 were engaged in running log likelihood program. The log likelihood yielded the parameters that were used in developing the logit model coefficient and convergence was attained after seven iterations of the model. Out of the twelve variables used, only the ones with significant coefficient were actually used in interpreting the model. The coefficients are shown in **Table 1**.

Table 1: A binary logit model coefficients and their significance (twelve drivers)
*Statistically insignificant drivers, P values higher than 0.05

Drivers						95% C.I for Exp. (β)	
	Coefficients (β)	Standard Error	DF	(α=0.05)	Exp.(β)	Lower	Upper
Travel Time (β_1)	-0.11240823	-0.0042715	1	0.027	0.8936794	0.7336794	1.0836794
Travel Fare (β_2)	-0.02901798	-0.0011317	1	0.012	0.9713989	0.831399	1.141399
Capacity (β_3)	0.03119710	0.0011231	1	0.011	1.0316888	0.8716888	1.2216888
Income (β_4)	0.00005012	1.704E-06	1	0.021	1.0000501	0.8600501	1.1700501
Education (β_5)	0.00310682	0.0001181	1	0.311*	1.0031116	0.8831117	1.1231117
Occupation (β_6)	0.01610235	0.0006312	1	0.167*	1.0162327	0.8762327	1.1462327
Purpose of Journey (β_7)	0.01880138	0.0006894	1	0.182*	1.0189792	0.8589792	1.1689792
Gender (β_8)	0.00707108	0.0002498	1	0.534*	1.0070961	0.8670961	1.1770961
Age (β_9)	0.01711966	0.0006871	1	0.145*	1.0172670	0.897267	1.167267
Aesthetic (β_{10})	0.18904502	0.0073728	1	0.389*	1.2080953	1.0480953	1.3380953
Comfort (β_{11})	1.23881401	0.0507666	1	0.337*	3.4515175	3.3115176	3.6215176
Traffic Safety (β_{12})	0.26017411	0.010407	1	0.031	1.297155	1.183678	1.301678
Intercept (β_0)	-0.69310162	-0.0228723	1	0.541	0.5000235		

Max. Log likelihood = -1450.498

Moreover, **Table 1** shows that only five variables were significant in the modal split logit model based on p-value (α=0.05). These variables are: Total Travel time (x_1); Travel fare (x_2); Capacity (x_3); Income of commuters (x_4) and Traffic safety (x_{12}). The negative log likelihood (-ln (likelihood)) of the logit model for this study was -1450.498 as indicated in **Table 3**. This is a measure of consistency between the data and the logit model developed for this study. It is the probability that the data set will produce a good logit model. The probability is usually very large but less than 1. Thus, natural logarithm of the likelihood value is taken, since the probability is less than 1, the logs are always negative. The negative log likelihood value of -1450.498 suggests a good fit between the logit model and raw data as indicated in **Tables 2 and 3** respectively.

Table 2: Omnibus Tests of Model Coefficients

		Chi-square	df	Sig.
Step 1	Step	1448.400	12	0.000
	Block	1448.400	12	0.000
	Model	1448.400	12	0.000

Table 3: Model Summary

Step	-2 Log likelihood	Cox & Snell R Square	Nagelkerke R Square
1	1450.498[a]	0.178	0.217

The logit coefficients of three out of the five significant variables have positive values. Therefore, income, capacity and traffic safety have positive effects on the choice of higher occupancy ferry, as it discourages the use of private cars and support higher occupancy buses by commuters with minimum traffic congestion. Since travel fare and travel time have negative logit coefficient, the utility of waterway index increases with reduction in travel fare and no congestion. Similarly, road travel fare and travel time with negative logit coefficient indicates that the utility of roadway increases with reduction in travel cost and travel time. Furthermore, in logistic regression there is no true R^2 value as in ordinary least square regression. The most common assessment of overall model fit in logistic regression is the goodness-of-fit test, which is simply the Chi-squares. In this study, Chi-squares was used to evaluate Model goodness-of-fit test as indicated in **Table 4.**

Observation from respondents on Socio-economic attribute: Occupation, Purpose of the journey, volume of traffic along the routes and causes of traffic congestion are shown in **Figures 3-5**.

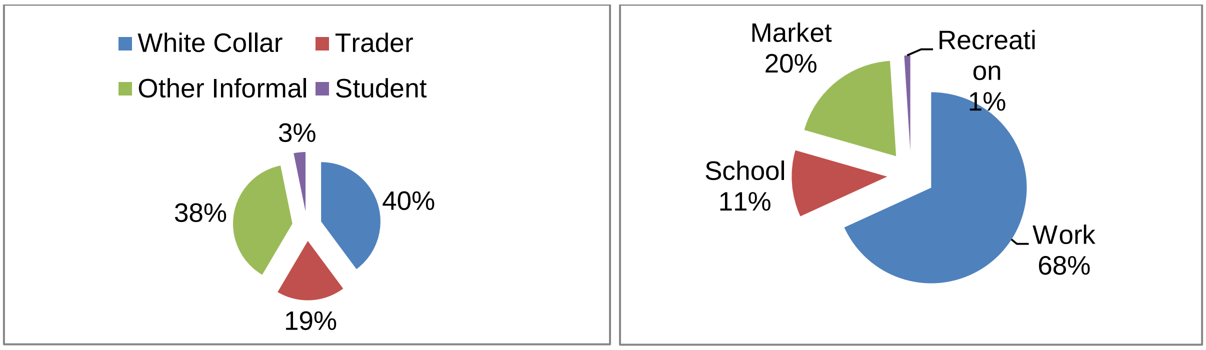

Figure 3: Occupation Structure of littoral residents and Percentage of purpose of the journey

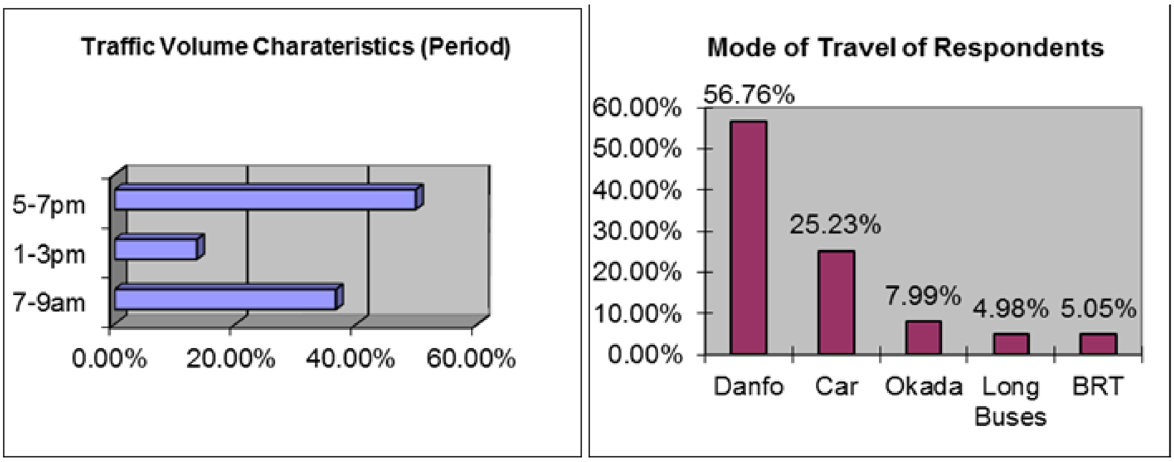

Figure 4: Volume of traffic along respondent's route and Mode of travel

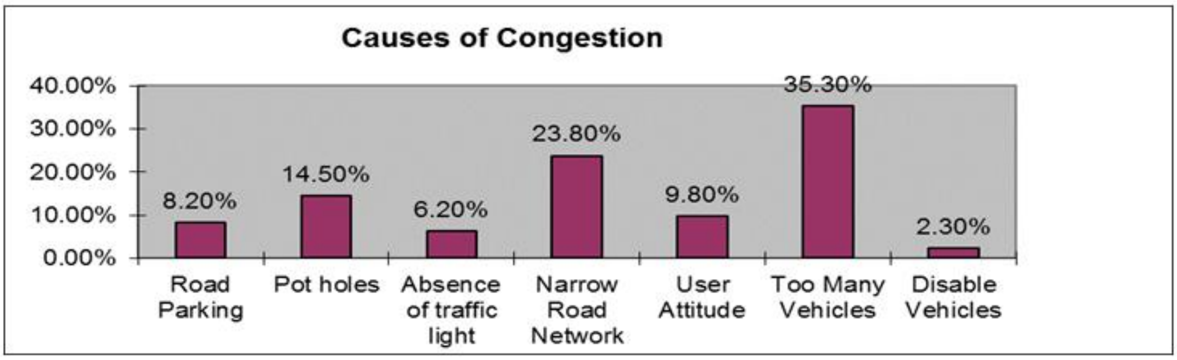

Figure 5: Causes of traffic congestion along the routes

Furthermore, chi-square test was used to determine the statistical significance of all the parameters to utility (modal split analysis). The chi-square statistic tests, the null hypothesis indicate that all coefficients are zero apart from the constant. The null hypotheses $H_0: \beta_1 = \beta_2 = ... = \beta_{12} = 0$; Alternative hypothesis $H_i: \beta_i \neq 0$ (at least one of the parameters): where β_1 … β_{12} are the coefficients presented in **Table 1**. The condition for rejecting the null hypothesis is: Reject H_0 : if $\chi_C{}^2 > \chi^2_{\alpha=0.05,\text{df}}$

The result of this test is as presented in **Table 4**. Chi-square results show that the null hypothesis is hereby rejected i.e. there is a significant effect of these parameters in the final model.

Table 4: Chi-square test results

Test	Degrees of freedom	χ^2 Computed(χ^2_C)	χ^2 Table (χ^2_T)
Chi-square	12	1448.400	21

In addition, the model output is in form of probabilities as shown in Eq. 9. It is therefore, expected to yield probability values between 0 and 1, as depicted in **Figures 6-7**. This is in form of bimodal logit curves as highlighted in Section 2. Therefore, **Figure 6** shows the probabilities of trips by roadway and waterway plotted against the marginal differences in utility for road (vehicles) and water (ferry) with respect to five significant parameters (travel time, travel fare, capacity, traffic safety and low income commuters).

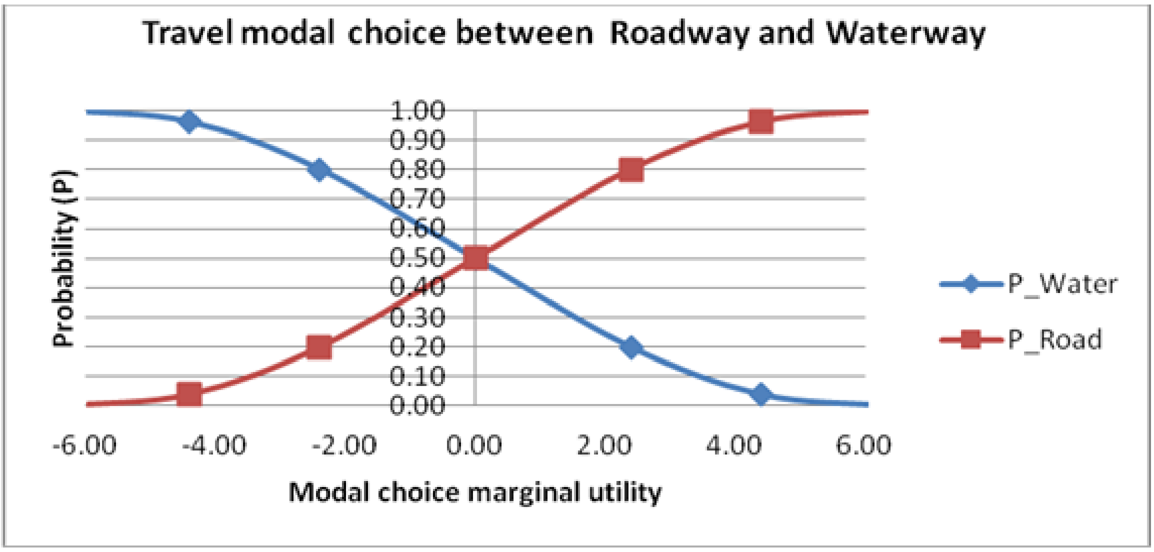

Figure 6: The logit function curve for low income commuters

Figure 7 shows the probabilities of trips by roadway and waterway plotted against the marginal differences in utility for road vehicles and water ferry with respect to five significant parameters (travel time, travel fare, capacity, traffic safety and high income commuters).

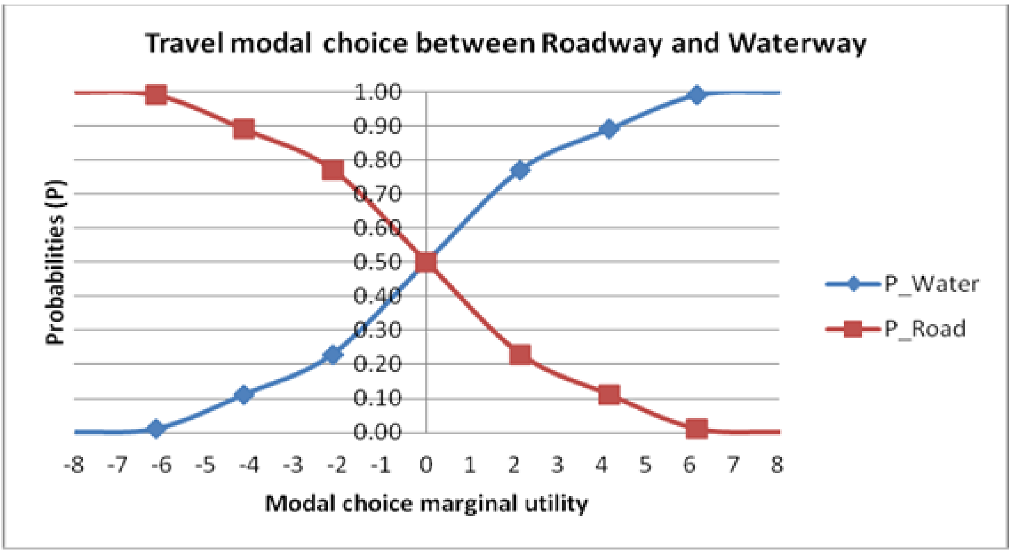

Figure 7: The logit function curve for high income commuters

4.0 CONCLUSION

The binary logit models developed for low income and high income commuters through the use of preference survey are useful to estimate likely ridership as a result of the shift from the existing modes of travel by the commuters to higher capacity transit system. It was established that five out of the twelve drivers evaluated were statistically significant to modal split analysis. The results of choice probability determined with this model can be a guideline for decision maker to promote the choice and preference of waterway in order to reduce roadway traffic congestion along the study corridors. Traffic switching between the roadway and waterway routes has a major impact on both the benefits and challenges. The better a mode is the more utility it has for the potential traveller. However, modes are said to be relatively more desirable if they are cheaper, faster, comfortable, or have other more favourable features than competitive modes. Littoral residents are more likely to use waterway because, it is stress free, convenient, smooth and congestion free than buses, private car, BRT services and increases the waterway user utility. It is important for boat operators to look out for signage in and near navigable waters, and comply with all navigational restrictions. Furthermore, the findings from this study if utilized will enhance efficient transportation in terms of both infrastructure and services in the city of Lagos and provide sustainable solutions to transportation services within the Metropolis. Government should invest in navigation lightening system, navigable signals and navigational aids to ease traffic congestion on Lagos road.

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