The Role of Road Network Characteristics in Travelers' Route Choice: A case of Colombo, Sri Lanka

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This study contributes to the literature on route choice modeling through an empirical examination of the effects of road network characteristics. The main objective of this study is to explain travelers' route choice behavior of motorized movements by the mode based on road network characteristics and investigate the influence based on their different levels of knowledge and understanding of the network; and journey length. This research is built on travelers' movement traces which have been collected by a study conducted in Colombo, Sri Lanka. 500 travelers were asked to record all the journeys they took for their day-to-day activities during a period of one week using Open Source Mobile GIS application imbedded to cell phone. The study has been used 'distance' of selected route in terms of 'metric distance', 'topological distance' and 'geo-metric distance' and to measure the centrality of selected route considering 'Connectivity', 'Closeness' and 'Betweenness' as road network characteristics. Relationship between travelers' route choice and road network characteristics of each route were analyzed with Logistic Regression Model. The results revealed that the claim of shortest cost path in terms of travel time is not always the most significant factor in travelers' route choice. Shortest path in terms of metric distance has become the most significant factor of the travelers who use taxi whereas travel time has becomes a less-significant factor. Travelers who do not have very good knowledge or experience on route -less frequent travelers- are less sensitive to travel time. Furthermore, results indicate that betweenness centrality is not significantly determined by travelers' knowledge or experience on a given route.

Key Words : *choice, road network characteristics, behavior cognition, travel time, mobile GIS*

1. INTRODUCTION

Travelers do choose and follow a range of routes within the complex environment [1)] while modeling driver route-choice behavior and development of navigation system have extensively focused on identifying and quantifying the most suitable or optimal path for travelers [2)] in the fields of traffic and transport planning and engineering. Accordingly, the process in which travelers perceive, memorize, evaluate and choose from the best or the most preferable route of travel has been the main focus in route choice modeling. 'Rational behavior theory' referring to the domain of traffic assignment explains that individual travelers select the best route that maximizes their utility by comparing all possible alternatives and measuring their attributes. As explained in 'Wardrop's user equilibrium theory', travelers are assumed to choose the route which has the shortest travel time [3)- 4)]. Accordingly, distance and travel time (either free-flow or estimated travel time) are commonly used in the utility functions of the route choice modelling while assuming that travelers choose the shortest time paths. Turner & Dalton [5)] explained that, utility function of route choice molding is a complex item comprising many factors and it differs by people to people based on their different levels of knowledge and understanding of the network. Recent researches explain that trip length, travel time, traffic congestion and environmental qualities are contributed to the travelers' utility.

However, another cluster of studies including works of Zhang [6)], Turner & Dalton [5)],Jan, Horowitz, & Peng [7)], Tversky [8)] highlighted that utility function develops based on length, congestion, travel time are far away from actual situation and has been overlooked the traveler's own perceptual and cognitive understanding of the road network. Further, Hillier's works in 'Cities as movement economics' argued that movement of both pedestrians and vehicles are driven by topological properties rather metric properties of transport networks [9)]. At the same time, Chiaradia pointed that "models have traditionally characterized network performance in terms of an average travel time associated with each link in the network, which varies according to the level of traffic using the link while ignores the influence of road network characteristics (i.e. network geometry) on route choice behavior" [10)]. Further to this, recent researches which have been carried out by Cutini [11)], Holme [12)], Crucittia, et al., [13)], Hillier & Iida, [9)], Altshuler, et al., [14)], Jiang & Jia, [15)], Galafassi & Bazzan [16)] and Jiang, et al., [17)] highlighted the importance of considering the road network characteristics in the process of modeling or simulating traffic flow patterns.

Despite the importance of simple travelers' route choice model which explains how travelers search for and select routes based on individual and transportation system characteristics; and develop more "human like" navigation systems, little research has been published in the fields of traffic and transport engineering and panning. Accordingly, this study contributes to the literature on route choice modeling through an empirical examination of the effects of road network characteristics. The main objective of this study is to explain travelers' route choice behavior of motorized movements by the mode based on road network characteristics and investigate the influence based on their different levels of knowledge and understanding of the network; and journey length.

2. METHOD OF STUDY

(1) Study area

The study conducted in Colombo Metropolitan Area (CMA), which is the main urban agglomeration area in Sri Lanka. CMA is one of the emerging urban agglomerations in South Asia with 5.8 million residential population and its account 30% of the country's population [18)]. **Table 1** gives a brief description about the traffic and transport characteristics of CMA area.

Table 1 Traffic and transport characteristics of the CMA area

Mode	Modal Share	Average Journey Length (km)
Public Transport	40.4%	13.2
Three Wheeler	12.9%	4.1
Motorcycle	14.1%	6.7
Car	11.1%	7.6

(2) Data collection

This research is built on travelers' movement traces which have been collected by a study conducted in CMA, from January 2015 to May 2015. 500 travelers were asked to record all the journeys they took for their day-to-day activities during a period of one week. To collect movements traces, the study used Open Source Mobile GIS (OSM-GIS) application imbedded to cell phone and participants were asked to switch on the mobile tracking application, which was installed in their cell phones, in all the journeys they took for their day-to-day activities. Each participant completed a survey form which was designed to gather data about socio-economic characteristics of the respondents and their familiarity to the area. 6,147 individual movement traces were collected from the survey and stored in a computer as GIS shape files. Then, the GIS database on movement traces was developed and adjusted to the actual GIS database of the road network of the study area eliminating spatial errors. Then routes were categorized into 33 O-D pairs representing key origins and destinations within the study area. **Table 2** summarizes the characteristics of the sample.

Table 2 Characteristics of the sample

Mode	%
Car	29
Motorcycle (MC)	24
Taxi	24
Public Transport (PT)	23
Sex	**%**
Male	63
Female	37
Age	**%**
<20	5
20-30	22
30-40	25
40-50	23
50-60	20
>60	5
Income level in Sri Lankan Rupees	**%**
<10,000	12
10,000-25,000	43
25,000-50,000	37
>50,000	08

Road network data were collected from secondary sources and stored in ArcGIS database. **Table 3** gives a brief discerption about those data.

Table 3 Road network data

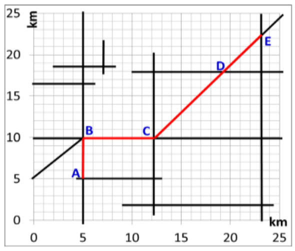
Data Type	Source	Description
Road net-work	Survey Department, Sri Lanka (2010)	Road centerline, Include the type of road as A-class, B-Class, C-Class and D-Class
Vehicle flow speed	JICA Report 19)	Link source, Daily average speed Moning and evening peak time speed

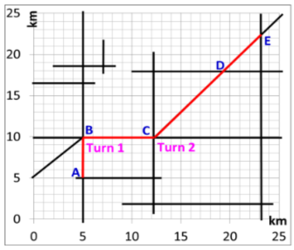
(3) Road network characteristics

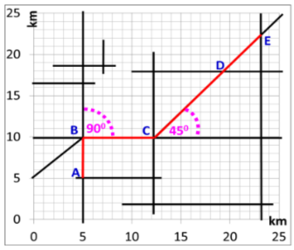
As mentioned above, the objective of this study is to explain travelers' route choice behavior of motorized movements by the mode based on road network characteristics and investigate the influence based on their different levels of knowledge and understanding of the network; and journey length. Hence, the study has been used ‘distance’ of selected route in terms of ‘metric distance’, ‘topological distance’ and ‘geo-metric distance’ (refer **table 4** for method of calculation) and to measure the centrality of selected route considering ‘Connectivity’, ‘Closeness’ and ‘Betweenness’ as road network characteristics.

This study used ‘Road Segments’ graph which has been introduced to represent road network by Turner [20] and calculated (refer **table 5** for method of calculation) the above mentioned road network characteristics by using Spatial Design Network Analysis (sDNA) extension in ArcGIS software application.

Table 4 Method of calculation – Distance of the route

<table>
<tr><th>Parameter</th><th>Definition</th><th>Method of calculation</th></tr>
<tr><td>Metric distance*</td><td>The shortest metric distance between two points</td><td>

Distance of the Route$_{AE}$
= 5+7+10.6+5.7
= 28.3km</td></tr>
<tr><td>Topological distance*</td><td>The fewest turns between two points</td><td>

Distance of the Route$_{AE}$
=Turn at B + Turn at C
= 2</td></tr>
<tr><td>Geo-metric distance*</td><td>The least angle change between two points</td><td>

Distance of the Route$_{AE}$
= 90/180×2 + 45/180×2
= 1.5</td></tr>
</table>

Note: *as introduced by Xia[20]

Table 5 Method of calculation – Centrality of the route

Parameter	Definition	Method of calculation
Connectivity*	The level of connectivity refers to the number of links to which the particular link is directly connected	$C_i = k$ $C_x = \sum_{n=1}^{n} C_i$ C_i = Connectivity of link i in road network of the study area, k = number of direct connections to link I, C_x= Sum of connectivity of all links in route x.
Closeness Centrality*	Level of closeness refers to the extent that a given link closes to all other links in the network.	$CC_i = 1/\sum_k d_{ik}$ $CC_x = \sum_{n=1}^{n} CC_i$ CC_i = Closeness of link i in road network of the study area, d_{ik}= shortest-path between link i and line k, CC_x= Sum of closeness of all links in route x
Betweenness Centrality*	Level of betweenness refers to the extent a given link belongs to the shortest-path between any pairs of two links in the network	$BC_i = \sum_j \sum_k \frac{d_{jk}(i)}{d_{jk}}$ $BC_x = \sum_{n=1}^{n} BC_i$ d_{jk} = shortest-path between link j and link k, $d_{jk}(i)$=shortest-path containing links i between link j and link k, BC_x= Sum of betweenness of all links in route x

Note: *as introduced by Hillie & Iida [9], shortest-path was calculated in terms of metric distance, topological distance' and geo-metric distance

(4) Route choice rules

Study hypothesized that travelers' select route while maximize the general cost of the route in terms of following factors.

1. Metric distance of selected route (MD)
2. Topological distance of selected route (TD)
3. Geo-metric distance of selected route (GMD)
4. Sum of connectivity of all links in selected route (C)
5. Sum of closeness which calculate in terms of metric distance of all links in selected route (MD_CC)
6. Sum of closeness which calculate in terms of topological distance of all links in selected route (TD_CC)
7. Sum of closeness which calculate in terms of geo-metric distance of all links in selected route (GMD_CC)
8. Sum of betweenness which calculate in terms of metric distance of all links in selected route (MD_BC)
9. Sum of betweenness which calculate in terms of topological distance of all links in selected route (TD_BC)
10. Sum of betweenness which calculate in terms of geo-metric distance of all links in selected route (GMD_BC)
11. Travel time at peak hour (TTP)
12. Average travel time (TTA)
13. Road condition (RC)

Accordingly, General cost of route (C) is computed as followers.

$$C = a*1/MD + b*1/TD + c*1/GMD + d*C + e*MD\_CC + f*TD\_CC + g*GMD\_CC + h*MD\_BC + i*TD\_BC + j*GMD\_BC + k*1/TTP + l*1/TTA + m*RC \quad (1)$$

One basic assumption in route choice model is that not all drivers use the optimal general cost route but all routes available between O-D can be used. Accordingly, more travelers' should be used optimal route compare to other routes. Accordingly, optimal route is select based on utility of the route. Study used as a utility function the reciprocal of the general cost;

$$U_j = \frac{1}{C_j} \quad (2)$$

U_j=utility of route j, C_j=general cost of route j

The wieldiest used model to analyzed discrete choice behavior is the Logit function;

$$p(R_j) = \frac{e^{\mu U_j}}{\sum_i e^{\mu U_i}} \quad (3)$$

U_j=utility of route j, $p(R_j)$=probability of route j to be chosen, μ=sensitivity factor of the model (>0)

Sensitivity factor of the model is determines how much the distribution reacts to differences in the utilities. But very low factor would lead to a rather negligible variation with no or very low impact on utility. If study uses the Logit function with a utility function as indicated in equations (2) model considers the difference between 7010m and 7020m of metric distance same as the difference between 10m and 20m, since the Logit function is invariant against translation and considers only the absolute difference of the utilities. To avoid that study used the 'Kirchhoff' [21] distribution formula,

$$p(R_j) = \frac{e^{-klogC_j}}{\sum_i e^{-klogC_j}} \tag{4}$$

C_j=general cost of route j, k=sensitivity factor of the model

3. ANALYSIS AND RESULTS

Initial analysis indicated that values of 13 factors couldn't be directly compared as they are in different scales. Therefore, study used Z score standardized the values of 13 factors. Relationship between travelers' route choice and road network characteristics of each route were analyzed with Logistic Regression Model (LRM). LRM was formed in which the selected route was denoted with 1 and non-selected with 0 use to evaluate the level of significance of each factor on travelers' route choice. To provide a better explanation results were categorized by mode of travel. LRM is developed corresponding to 95% confidence interval.

(1) Travelers who travel by car

Table 6 summarizes the model results.

Table 6 Summary of LRM results - Travelers who travel by car

Factors	Frequent travelers* (FT) Sig.	Frequent travelers* (FT) Exp(B)	Less frequent travelers** (LFT) Sig.	Less frequent travelers** (LFT) Exp(B)
1/MD	0.0070	1.08	0.1501	1.07
1/TD	0.0000	2.01	0.0210	1.01
1/GMD	**0.0001**	**4.86**	**0.0001**	**1.14**
C	0.0520	1.00	0.0321	1.10
MD_BC	0.0051	2.17	0.0540	1.17
MD_CC	0.2790	1.04	0.3790	1.09
GMD_BC	**0.0000**	**4.66**	**0.0000**	**5.46**
GMD_CC	0.0071	2.49	0.0011	3.28
TD_BC	0.0000	1.05	0.0210	1.50
TD_CC	0.0000	2.02	0.0020	2.40
1/TTP	**0.0000**	**4.04**	**0.0310**	**1.44**
1/TTA	0.0000	1.01	0.1100	1.24
RC	0.0000	1.98	0.0501	1.24

Note: LRM predictability for selecting route (1) for FT is 69%* and LET is 64%**

According to the results obtained from analyzing the frequent travelers who travels along each O-D pair, shortest path in terms of geo-metric distance (Exp(B) = 4.86, sig. 0.0001), betweennees centrality in terms of geo-metric distance (Exp(B) = 4.66, sig. 0.0000) and travel time at peak hours (Exp(B) = 4.04, sig. 0.0000) are appeared as key factors which influence on route choice of travelers who travel by car compare to other factors.

When it comes to the less frequent travelers, betweennees centrality in terms of geo-metric distance have become the key factor for travelers who travel by car (Exp(B) = 5.46, sig. 0.0000) while travel time at peak hour (Exp(B)=1.44, Sig 0.0310) and geo-metric distance (Exp(B) = 1.14, sig. 0.0001) become less important factor compare to betweennees centrality.

(2) Travelers who travel by motor cycles (MC)

Table 7 summarizes the model results.

Table 7 Summary of LRM results - Travelers who travel by MC

Factors	Frequent travelers* (FT) Sig.	Frequent travelers* (FT) Exp(B)	Less frequent travelers** (LFT) Sig.	Less frequent travelers** (LFT) Exp(B)
1/MD	0.1100	1.00	0.3000	1.01
1/TD	**0.0000**	**5.32**	0.0002	2.24
1/GMD	0.0070	1.37	0.0007	1.64
C	0.0000	0.00	0.0000	0.00
MD_BC	0.0000	1.36	0.0020	0.36
MD_CC	0.0000	0.00	0.0000	0.00
GMD_BC	**0.0000**	**4.53**	**0.0000**	**3.32**
GMD_CC	**0.0001**	**4.28**	0.0021	2.92
TD_BC	0.0880	1.06	0.1830	1.03
TD_CC	0.0000	2.40	0.0360	1.95
1/TTP	**0.0020**	**2.81**	**0.0090**	**1.08**
1/TTA	0.0000	1.02	0.0120	1.21
RC	0.0031	1.05	0.1030	1.03

Note: LRM predictability for selecting route (1) for FT is 76%* and LET is 72%**

The travelers who travel by motorcycles, the shortest path in terms of topological distance (Exp(B) = 5.32, sig. 0.0000), betweennees centrality in terms of geo-metric distance (Exp(B) = 4.53, sig. 0.0000) and closeness centrality in terms geo-metric distance (Exp(B) = 4.28, sig. 0.0001) are appeared as key factors whereas travel time at peak hours (Exp(B) = 2.81, sig. 0.0020) has obtained comparatively low level of importance.

Further, betweennees centrality in terms of geo-metric distance have become the key factor for frequent travelers (Exp(B) =3.32, sig. 0.0000) while travel time at peak hour (Exp(B)=1.08, Sig 0.0090) become less important factor compare to betweennees centrality.

(3) Travelers who travel by taxi (MC)

Table 8 summarizes the model results.

Table 8 Summary of LRM results - Travelers who travel by taxi

Factors	Frequent travelers* (FT) Sig.	Exp(B)	Less frequent travelers** (LFT) Sig.	Exp(B)
1/MD	**0.0010**	**6.46**	**0.0011**	**6.66**
1/TD	0.0000	0.00	0.0100	0.01
1/GMD	0.0000	1.53	0.0231	1.33
C	0.0000	1.80	0.0020	1.51
MD_BC	0.0000	1.23	0.0111	1.33
MD_CC	0.0040	2.20	0.0040	2.90
GMD_BC	0.0000	1.97	0.0010	1.70
GMD_CC	0.0020	1.20	0.1120	1.40
TD_BC	0.0000	1.08	0.0101	1.05
TD_CC	0.1410	0.00	0.1114	0.00
1/TTP	0.0000	1.11	0.0010	1.02
1/TTA	0.0000	1.09	0.0021	1.01
RC	0.0000	2.10	0.0020	2.20

Note: LRM predictability for selecting route (1) for FT is 60%* and LET is 63%**

Regarding, travelers who travel by taxi shortest path in terms of metric distance (Ex, FT scenario, Exp(B) = 6.46, sig. 0.0010 and LFT scenario, Taxi Exp(B) = 6.66, sig. 0.0011) indicate very significant influence on route choice compare to other factors in both the scenarios.

3. CONCLUSIONS AND WAY FORWARD

Accordingly, the findings of this study on one hand strengthen some of the arguments put forward by previous studies and on the other hand make novel contribution on the domains of studies related to travelers' route choice modeling. The results revealed that the claim of shortest cost path in terms of travel time is not always the most significant factor in travelers' route choice. Shortest path in terms of metric distance has become the most significant factor of the travelers who use taxi whereas travel time has becomes a less-significant factor. Travelers who do not have very good knowledge or experience on route -less frequent travelers- are less sensitive to travel time. Hillier and Iida[11)] as well as Turner[28)] have found that human beings perceive the space mostly from geo-metric distance rather than metric distance. The results of this study too revealed a similar kind of relationship. Further, previous studies of Puzis, et al and Galafassi & Bazzan has argued that, 'choice' (similar to betweenness) which is computed based on geo-metric analysis method significantly influence in predicting traffic volume and 'choice' (similar to betweenness) should form a better model of movement data than closeness centrality parameter [11)]. This study also found a similar kind of relationship in case of travelers who use car and motorcycles while travelers who use taxi were more sensitive to closeness centrality factor compare to betweenness centrality. Furthermore, results indicate that betweenness centrality is not significantly determined by travelers' knowledge or experience on a given route.

In forthcoming works, the authors are working to extend the investigation described here to analysis influence of above mentioned factors on travelers' route choice with the journey length. Subsequently, authors is going to create robust and accurate generalized-cost representation for travelers' mode choice that can be integrated into a broader traffic forecasting framework.

REFERENCES

1) Golledge, R. G.: Path Selection and Route Preference in Human Navigation: A Progress Report, *The University of California Transportation Center*, Berkele, 1995.
2) Bovy, P. H. L., and Stern, E.: Route Choice: Wayfinding in Transport Networks, *Kluwer Academic Publishers*, Dorfrecht, p. 9, 1990.
3) Wardrop, J. G.: Some Theoretical Aspects of Road Traffic Research, *Institute of Civil Engineers*, London, 1952.
4) Vreeswijk, J., Thomas, T., Berkum, E. v., and Arem, B. v. : Drivers' Perception of Route Alternatives as Indicator for the Indifference Band, Transportation Research Record: Journal of the Transportation Research Board, *Transportation Research Board of the National Academies*, Washington, D.C., Vol. 2383, p. 10–17., 2013.
5) Turner, A., and Dalton, N.: A simplified route choice model using the shortest angular path assumption, *Proc. of the 8th International Conference on GeoComputation*, Michigan, USA, 2005.
6) Zhang, L.: The Behavioral Foundation of Route Choice and Traffic Assignment, Transportation Research Record: Journal of the Transportation Research Board, *Transportation Research Board of the National Academies*, Washington, D.C., Vol. 2254.1, pp. 1-10, 2011.
7) Jan, O., Horowitz, A. J., and Peng, Z.: Using GPS data to understand variations in path, Transportation Research Record , *Transportation Research Board of the National Academies*, Washington, D.C., Vol. 1725, pp. 37-44, 2000.
8) Tversky, B.: Distortions in cognitive maps, *Geoforum*, Vol. 23, pp. 131-138, 1992.
9) Hillie, B., and Iida, S.: Network and psychological effects in urban movement, *Proc. of Spatial Information Theory: International Conference*, Berlin, 2005.
10) Chiaradia, A.: Emergent Route Choice Behaviour, Motorway and Trunk Road Network: the Nantes conurbation, *Proc. of the 6th International Space Syntax Symposium*, İstanbul, 2007.
11) Cutini, V.: Configuration and Centrality: Some evidence from two Italian case studies, *Proc. 3rd International Space Syntax Symposium Atlanta*, Atlanta, 2001.
12) Holme, P.: Congestion and centrality in traffic flow on

complex networks, *Advances in Complex Systems: A Multidisciplinary Journal*, Vol. 6, No. 2, pp. 163-176, 2003.
13) Crucittia, P., Latorab, V., and Marchioric, M.: Topological analysis of the Italian electric power grid, *Physica A: Statistical Mechanics and its Applications*, Vol. 338, No. 1-2, pp. 92-97, 2004.
14) Altshuler, Y., Puzis, R., Elovici, Y., Bekhor, S., and Pentland, A: Augmented Betweenness Centrality for Mobility Prediction in Transportation Networks, *Proc. International Workshop on Finding Patterns of Human Behaviors in NEtwork and MObility Data (NEMO)*, Athens, 2011.
15) Jiang, B., and Jia, T.: Agent-based simulation of human movement shaped by the underlying street structure, *Journal of Geographical Information Science*, Vol. 25, No. 1, pp. 51-64, 2011.
16) Galafassi, C., and Bazzan, L. C.: Analysis of Traffic Behavior in Regular Grid and Real World Networks, *Porto Alegre*, Brazil, 2014.
17) Jiang, B., Yin, J., and Zhao, S.: Characterizing the Human Mobility Pattern in a Large Street Network, *Cornell University Library*, Gävle, 2014.
18) Department of Census & Statistics-Sri Lanka: Census of Population & Housing-2011, *Department of Census & Statistics, Sri Lanka.*, 2012.
19) JICA: Final Report - CoMTrans Urban Transport Master Plan, *Japan International Copperation Agency (JICA)*, 2014.
20) Xia, X.: A Comparison Study on a Set of Space Syntax based Methods: Applying metric, topological and angular analysis to natural streets, axial lines and axial segments, *Department of Geomatics, University of Gävle*, Gävle, 2013.
21) Verkehr, A. G.: VISSIM4.10 User Manual, *PTV Planung Transport*, Karlsruhe, 2005.

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