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Road Network-based Determinants of Travel Demand

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Abstract

Road network has a key role in defining the urban structure of a city. The question of how travel demand varies with the road network design is particularly important, as it is the slowest urban system to alter. As the network structure prevails for a long duration, and its modification in a short time is rather difficult, it is essential to obtain an optimal network design. This paper examines the effect of the road network on travel demand, in the realm of developing nations, based on the characteristics of Calicut city, Kerala. Various network characteristics including fractal dimension, have been quantified so as to identify their influence on travel. This study, being the first of its kind in India, confirms that the network characteristics influence the number of trips and travel by various modes. The estimation results are expected to shed light on how network design can reduce travel.

Keywords: Network Structure; Connectivity; Urban; Travel.

1. Introduction

Travel related problems such as traffic congestion and accidents are experienced in most of the developing countries, mainly due to the restricted road capacity and exponential growth of traffic. The environmental concerns and health issues due to the enormous private vehicles moving on the road, add to the need for controlling the travel. The transportation network, particularly road-based, plays a key role in the overall development of a city. Because of the huge developmental cost of the road network, effective utilisation is essential, which can be attained only when the network is properly designed. While past studies analysed the interaction between urban structure and travel demand, recent studies have focused on the interaction between road network structure and travel (Parthasarathi, 2011; Parthasarathi and Levinson, 2018). Network structure, including connectivity and arrangement of road stretches, and their influence on travel were the focus of these network-travel studies.

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Fractal dimension, being the network characteristic that indicates the spatial location of road stretches, has not been included in any studies examining the network influence on travel demand. Actually, while examining the role of network in defining travel, all the network aspects are to be included so as to arrive at an efficient network. Moreover, network-travel studies in the context of developing countries are absent. Variation in the travel characteristics of length and duration, due to variation in the network characteristics are also not been addressed till now. Hence, the main objective of the present study is to examine the effect of network structure in defining the travel demand of a location, using the data related to the medium-sized city of Calicut, India. Awareness of the interaction between the network and travel by different modes can help in developing guidelines for controlling the travel demand. Present study is a stepping stone in designing the road network so as to improve the network's performance.

2. Previous studies

The growing rate of dependence of individuals on private motor vehicles was a topic of concern, when examining the travel reduction strategies. Definitely, an urban road network determines the urban structure and, in turn, the travel and traffic within a city. In an earlier attempt, a few geographers examined the spatial nature of transport networks and their role in provincial growth (Rodrigue et al., 2006). Of the studies characterising the network, most of them considered density or connection pattern (Cervero and Kockelman, 1997). Few studies measured network in terms of accessibility or circuity (El-Geneidy and Levinson, 2007; Xie and Levinson, 2007). Yoshihiko (2000) analysed the road network influence on journey length, adopting fractal concept. The influence of network on transit mode choice has been confirmed by Derrible and Kennedy (2009).

On analysing the urban structure and travel, there seems to be a clear gap in considering various transport network aspects. Particularly, the influence of arrangement, connectivity, and capacity of road stretches on travel has been hardly studied. Considering the parameter of network circuity, the choice of residential location relative to the workplace based on shorter commutes has been confirmed by Levinson and El-Geneidy (2009). Parthasarathi et al. (2009) confirms the positive influence of nodal entropy and the negative influence of circuity on vehicle kilometres of travel. As per Huang and Levinson (2011), network topology affects the perceived travel time. Travel-increase due to the presence of freeways and travel-reduction due to network connections have been established in a few studies (Parthasarathi, 2011; Parthasarathi and Levinson, 2018). The effect of topology, heterogeneity, and scale of the network on such travel aspects as activity space, travel, and congestion level has been established (Parthasarathi, 2011). All these research works postulate the significant role of network design in travel decisions. However, an in-depth analysis is essential based on "whether the difference in the network structure can explain the difference in travel characteristics by various modes?"

Whatever the discussions that highlight the effect of network aspects on travel, these debates pertain to the cities of the United States. However, developed and developing cities differ in their demographic and environmental aspects. Again, a heterogeneous mix of vehicles moving in the same lane, with the dominating feature of motor vehicles in developing cities, differentiates the traffic in developing cities from that in developed ones. All these factors highlight the necessity of a separate study in a developing city context exploring the role of network structure on transport performance. This is essential because the underlying aim of any transportation study is to reduce the travel demand, and again, one possible way to reduce travel is to reduce the length and duration of trips. Understanding the network characteristics that cause a change in travel demand by different modes is an area that is yet to be explored. Again, the influence of network fractal dimension on trips in length and number has not been identified. Hence, what are the network-related strategies that can be introduced so as to minimise travel in developing country context is to be studied in detail.

The present study has included network characteristics such as density, diversity, connectivity, accessibility, circuity and fractal dimension so as to examine their influence on travel. A study of this kind has not been undergone in India, where traffic and travel are growing at a rapid rate. It is a fact that the design of the road transport network has always been a challenging task for transport planners. The question of how travel varies with road network structure is especially important because it is the most slowly changing urban system. As the network structure persists for a long duration, and its modification in a short time is rather difficult, it is essential to obtain an optimal network design. The transport network, when properly planned and designed, increases its capacity so as to accommodate the growing traffic and thus helps to attain mobility and sustainability. Improper planning of the road network and its stretches often manifests in the form of exorbitant delays along the busy corridors.

3. Characterisation of Network and Travel Demand

3.1 Road Network Characteristics

Various network aspects characterising the road network can be classified into:

- Connectivity: Alpha index, Beta index, Gamma index, GTP (Grid Tree Pattern index) and Eta index.
- Circuity: Network Circuity, Treeness.
- Diversity: Network entropy, Nodal entropy.
- Density: Network density, Intersection density.
- Accessibility: Network-based accessibility, Distance to Central Business District (CBD).
- Fractal dimension: Box dimension.

3.1.1 Connectivity

Connectivity indicates the configuration and physical connections within the network. It is quantified in terms of alpha index, beta index, gamma index, Grid Tree Pattern index (GTP) and eta index. Of these, the gamma index, proposed by Kansky (1963), is the most widely used and is found to have the highest correlation to the travel parameters. The gamma index (γ) compares the number of links to the maximum possible number of links in the network, as given in Equation (1). The values of gamma index vary from 0 (no connections between nodes) to 1 (maximum number of connections, with direct links between all the nodes).

$$\gamma = \frac{e}{3(v-2)} \qquad (1)$$

Where, e is the number of edges in the network;
v is the number of nodes/junctions in the network.

3.1.2 Circuity

The extent to which distance over existing route differs from that of direct-connected graph is defined as circuity. More direct the route between the destinations, the more efficient the road network will be. Circuity is measured by network circuity and treeness.

Network Circuity

Network circuity is the ratio of the actual network distance to the euclidean distance (Levinson and El-Geneidy, 2009). Even if a network is directly connected, it may be circuitous, and this deviation from the direct path is measured by network circuity.

Treeness

Treeness captures the difference in topology and connection pattern that exists in a network (Xie and Levinson, 2007). A branching network is defined as a tree-shaped structure, which is a set of connected links that do not form a complete circuit, and treeness is estimated as in Equation (2).

$$\varphi_{tree} = \frac{Total\ length\ of\ road\ links\ on\ branching\ network}{Total\ length\ of\ road\ network} \qquad (2)$$

3.1.3 Diversity

Diversity measures capture the relative abundance of the network components based on type. It is measured using nodal entropy (entropy of the nodes) and network entropy (entropy of the road links). Entropy, proposed by Shannon (1949), which defines the variation in a phenomenon within a system, is used in this study.

Network Entropy

Network entropy (H_{LW}) takes into consideration the variation in width of roads and is quantified using Equation (3).

$$H_{LW} = \frac{-1}{\ln(n)} \sum_{i=1}^{n} w_i\, p_i \ln p_i \qquad (3)$$

Where, *n* is the number of subsets in the system;
$p_i = l_i / L$, is the proportional length of the road having width *i*;
l_i is the length of road of width *i*, *L* is the total road length;
w_i is the weight assigned to the subset based on the number of lanes.

Nodal Entropy

Nodal entropy (H_{ND}) measures the heterogeneity among nodes based on the nodal degree (Parthasarathi et al. 2009) and is quantified using Equation (4).

$$H_{ND} = \frac{-1}{\ln(n)} \sum_{i=1}^{n} w_i \, p_i \ln p_i \qquad (4)$$

Where, n is the number of subsets in the system;
$p_i = n_i/N$, is the proportion of nodes of degree i;
n_i is the number of nodes of degree i, N is the total number of nodes;
w_i is the weight assigned based on the number of conflict points.

3.1.4 Density

Density refers to the concentration of road network components per unit area, and is measured by network density and intersection density. Network density is the total road length per unit area, and intersection density is the number of intersections per unit area.

3.1.5 Accessibility

The network's accessibility indicates the ease with which facilities and services can be accessed. It is used to evaluate how well a network links the destination, thus creating a more accessible and reliable transport network. It is measured in terms of network-based accessibility and distance to CBD.

Network-based Accessibility

It is a measure of how well a zone is connected to other zones, and it depends on the network structure. This is calculated using Equation (5).

$$A_i = \sum_{j} f(c_{ij}) \qquad (5)$$

Where, A_i is the accessibility of zone i;
$f(c_{ij})$ is the travel impedance function, and negative exponential function is chosen in this study;
c_{ij} is the travel time or travel cost between the zones i and j. Distance along the shortest path on the road network is considered in this study.

Distance to CBD

Distance to CBD is measured along the shortest route on the network, as considered in other studies (Zhao et al., 2016; Haozhi et al., 2018).

3.1.6 Fractal Dimension

Fractal dimension indicates how well the road stretches fill the study area, when zooming to finer levels (Batty and Longley 1994). Fractal dimension not only describes the system as a whole, but also its inner pattern and its gradual change in space, while other measures such as connectivity are unable to explain the system inner pattern. The box counting method is used here to estimate D, the fractal dimension as in Equation (6).

$$D= -\frac{ln\frac{N_i}{N_{i-1}}}{ln\frac{L_i}{L_{i-1}}} \tag{6}$$

Where, N_i is the count of grids of size L_i covered by the road network;
N_{i-1} is the count of grids of size L_{i-1} covered by the road network.

Grids of sizes 1000 m, 800m, 600m, 400m, 200m, 100m and 50m are prepared in GIS, and the count of grids covering the network is obtained. A double-logarithmic plot of grid size and grid count is drawn, and its slope gives fractal dimension.

3.2 Travel Characteristics

Travel is measured by number of trips, person-kilometre and person-hour. Travel in person-kilometres indicates the total distance travelled by the individuals, and travel in person-hours specifies the total time spent by the individuals for travel. For the analysis, these three travel parameters for all vehicles, as well as those for various modes of car, bus, and two-wheeler, are taken into account.

4. Methodology and Database Development

The study intends to assess how the road network's design influences travel. The methodology of this study includes selection of the study area, estimation of the network parameters for each zone, computation of travel by different modes for each zone, identification of the relationships among network and travel parameters through statistical analysis, and development of models relating travel and network variables.

The road network is characterised in terms of density, diversity, connectivity, accessibility, circuity and fractal dimension. Travel demand is characterised in terms of the number of trips, travel in person-kilometres and travel in person-hours. As travel characteristics vary depending on the mode of travel, zonal values of travel variables are computed for car, bus and two-wheeler.

4.1 Study Area

Calicut (Kozhikode) is a medium-sized city in the state of Kerala, India. The city is spread over 118.59 square kilometres, and the Central Business District (CBD) of the city is the zone of Palayam. Presently, there are 75 electoral wards under the Calicut Municipal Corporation, of which 68 zones are considered for the present study. The location map of Calicut Corporation, along with its zonal details, is shown in Figure 1. The residing population of the corporation area is 6.13 lakhs (as per the 2011 Census) with a density of 5,171 persons per square kilometre.

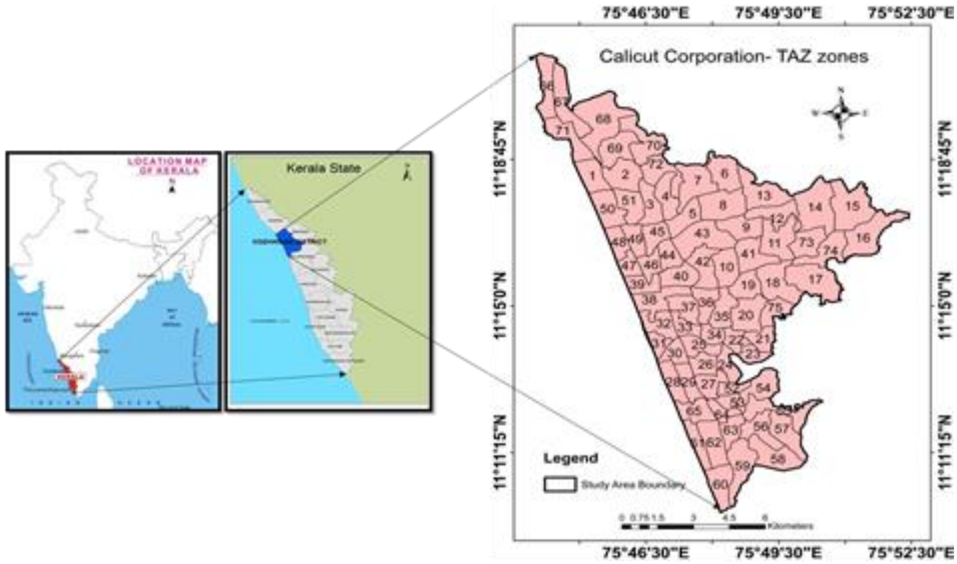

Figure 1. Location map of Calicut Corporation

Figure 2 shows the road network of the study area. The total length of the road network is 521 kilometres, with a road density of 4.42 kilometres per square kilometre. Some of these roads facilitate intercity trips and others facilitate intracity trips. The road stretches in and near the CBD, have lengths varying from 160 to 540 metres and widths varying from 3 to 7 metres. The outer zones have road stretches of 300 to 900 metres in length and 7 to 15 metres in width. The central zones have a denser road network, with an average network density of 14 kilometres per square kilometre. The outer zones have tree-like network structure with many dead ends, causing circuitous travel.

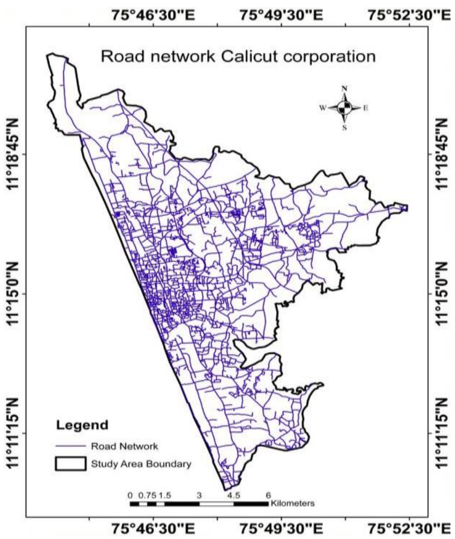

Figure 2. Road network map of Calicut Corporation

4.2 Database Development

The database collected includes zonal details, road network details and travel characteristics. A CAD drawing comprising details on zonal boundaries and the road network was obtained from Calicut Corporation Office. Using GIS software, the zonal boundaries and the road network were digitised, and the related attributes were added. Travel data was extracted from the one-day travel database for the residents of 9900 households, distributed in 68 wards of Calicut Corporation. The data was cleaned so as to eliminate the intra-zonal trips and external trips. The time and length of travel for each trip, and the mode of travel were obtained and compiled for later analysis.

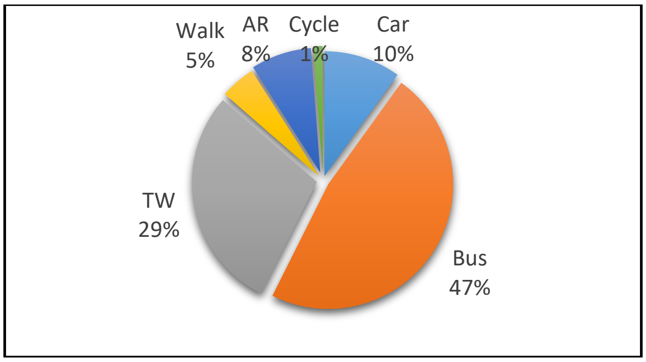

Figure 3. Modal share of trips

Figure 3 shows the mode split of trips. From the figure, it is clear that the major share of trips is by two-wheeler and bus (76%). As compared to the car ownership of the residents of the city of Calicut, the proportion of car choice riders is lower.

5. Quantification of Network and Travel Characteristics

The indices identified for characterising the network and travel demand are evaluated based on the database of the study area. Summary statistics of the travel measures are listed in Table 1, and those of the network measures are listed in Table 2.

The best road network variable under each category is identified by means of correlation analysis. Thus, the network indices identified for modelling travel demand include the gamma index, network circuity, network entropy, network density, and distance to the CBD. In addition, fractal dimension is also considered for modelling.

Table 1. Summary Statistics of travel variables

Variable	Minimum	Maximum	Mean	Std. Deviation
Number of trips (all)	2374	16695	6649	2471
Number of trips by bus	808	7040	3025	1240
Number of trips by car	0	1726	532	408
Number of trips by two-wheeler	263	2854	1603	647
Person-km by all vehicles	11285	115388	36686	17777
Person-km by bus	4815	63156	19529	10187
Person-km by car	0	9981	3355	2578
Person-km by two-wheeler	1003	18725	8717	4191
Person-hr by all vehicles	1068	8588	2844	1185
Person-hr by bus	369	3457	1507	665
Person-hr by car	0	777	226	173
Person-hr by two-wheeler	113	1258	606	261

Table 2. Summary Statistics of network variables

Measure	Variable	Minimum	Maximum	Mean	Std. Deviation
Connectivity	Alpha	0.04	0.78	0.44	0.18
	Beta index	1.00	2.52	1.77	0.37
	Gamma index	0.38	0.85	0.63	0.11
	GTP	0.30	1.90	1.18	0.39
	Eta index	12.23	334.85	112.25	59.12
Density	Network density (km/km^2)	1.20	16.53	6.15	3.43
	Intersection density ($/km^2$)	4.52	126.64	34.23	28.04
Circuity	Network circuity	1.02	2.06	1.38	0.33
	Treeness	0.03	1.00	0.51	0.36
Accessibility	Network accessibility	50.46	62.51	58.34	3.24
	Distance to CBD (km)	0.00	13.18	6.05	3.04
Diversity	Network entropy	0.07	3.96	2.11	0.94
	Nodal entropy	0.00	0.44	0.14	0.09
Fractality	Fractal dimension	1.004	1.542	1.192	0.141

Accordingly, regression models are developed to examine the influence of road network characteristics on travel demand, which is considered in terms of the number of trips, person-km of travel, and person-hr of travel. As the fractal dimension summarises the density and connectivity of the network, there is likely to be a multi-collinearity problem. Hence separate models with and without fractal dimension are developed.

6. Development of Travel Demand Prediction Models

The indices identified for characterising the network and travel demand are evaluated based on the database of the study area. Summary statistics of the travel measures are listed in Table 1, and those of the network measures are listed in Table 2.

6.1 All Trips

To understand the influence of network characteristics on travel demand, models are developed by linear regression modelling of transformed variables. Table 3 gives the results of model estimation. Here, travel undertaken by all the vehicle modes, is measured in terms of number of trips, person-km, and person-hr. Separate models are developed for number of trips (Model 1), person-km (Model 2) and person-hr (Model 3).

Table 3. Model estimation results for all trips

Variable	Number of trips Coeff. (t-value)	Person-km Coeff. (t-value)	Person-hr Coeff. (t-value)
exp (Gamma)	2591^{***} (4.77)	-8524^{**} (-2.36)	-818^{***} (-3.34)
exp (Network Circuity)	-415^{**} (-1.97)	5346^{***} (3.56)	337^{***} (3.31)
exp (Network entropy)	-0.78 (-0.03)	-92.40 (-0.43)	-6.66 (-0.47)
Network Density^{b}	-0.004 (-0.96)	-0.003 (-1.19)	-0.010 (-0.27)
exp (Distance to CBD)	-0.010^{**} (-2.08)	0.002 (0.15)	0.000 (20.94)
R-square	0.89	0.68	0.88
F-statistic	50.46	62.51	58.34

***Significant at 1% level; **Significant at 5% level; *Significant at 10% level
b= 4.67 for number of trips, 5.55 for travel in person-km., 4.19 for travel in person-hr

The R^2-value indicates the goodness of fit of the model, and the F-value indicates the explanatory significance of the model. Model 1 has an R^2-value of 0.89, which means that about 89% of the variance in the number of trips is explained by the network measures alone. In the case of person-km, 68% of the variance is explained by the network variables, and in the case of person-hr, 88% of the variance is explained. Hence, network measures are statistically relevant in predicting travel demand.

As shown in Table 3, network connectivity and circuity are the highly significant predictors ($p< 0.05$) of travel demand. The distance to CBD is significant with respect to the number of trips. The greater the connectivity, the more frequent the overall trips. Again, a well-connected road network causes the residents to travel shorter distances, as reported by Diao and Ferreira (2014), Ewing and Cervero (2010) and Wang et al. (2018). A circuitous network increases the length of trips. That is, when routes become circuitous, the travellers are forced to cover more distance and spend more time, which indicates the inefficiency of the system between origin and destination.

Table 4 gives the results of the modelling, including the fractal dimension as one of the explanatory variables. The model indicates that fractal dimension and network circuity show a significant relationship with travel. The road network's fractal dimension influences the number of trips positively. A network with a high fractal dimension temptes the residents to travel shorter distances, as reported by Yoshihiko (2000).

Table 4. Model estimation results of all trips (including fractal dimension)

Variable	Number of trips Coeff. (t-value)	Person-km Coeff. (t-value)	Person-hr Coeff. (t-value)
exp (Network Circuity)	-590.57*** (-3.13)	6301.21*** (4.83)	422.69*** (4.91)
exp (Network entropy)	-17.29 (-0.59)	-190.72 (-0.94)	-14.64 (-1.09)
exp (Fractal dimension)	1254.69*** (4.69)	-3755.50** (-2.03)	-363.04*** (-2.98)
exp (Distance to CBD)	-0.008* (-1.76)	-0.008 (-0.25)	0.00 (10.61)
R-square	0.85	0.68	0.88
F-statistic	69.37	62.68	76.84

***Significant at 1% level; **Significant at 5% level; *Significant at 10% level.

7. Travel Demand Prediction models for Different Modes

This section presents the results of analyses of the road network's influence on travel demand by various modes of transportation. This analysis was thought essential so as to better understand the influence of network characteristics on travel by the different modes. Travel modes considered here are bus, car, and two-wheeler.

7.1 All Trips

This section examines the predictive power of network characteristics on the number of trips by different modes. Table 5 presents the results of modelling the number of trips by bus, car, and two-wheeler.

Table 5. Model estimation results for number of trips by different modes

Variable	Bus Coeff. (t-value)	Car Coeff. (t-value)	Two-wheeler Coeff. (t-value)
exp (Gamma)	1001*** (3.96)	-381*** (-4.00)	640*** (4.27)
exp (Network Circuity)	-315*** (-3.01)	-63.3* (-1.68)	-83.24 (-1.34)
exp (Network entropy)	-3.13 (-0.22)	14.4*** (2.98)	3.87 (0.46)
Network Density^{b}	-0.020* (-1.86)	-0.61*** (-2.48)	0.002 (0.22)
exp (Distance to CBD)	0.002 (10.31)	0.001 (0.50)	-0.001 (-0.99)
R-square	0.89	0.70	0.86
F-statistic	93.92	28.50	74.65

***Significant at 1% level; **Significant at 5% level; *Significant at 10% level.
b= 4.21 for bus, 2.58 for car, 3.92 for two-wheeler

Zones with a well-connected network have more frequent trips by bus and two-wheeler, which may be due to the scope for direct travel. This is in agreement with the previous studies, that a well-connected network encourages the number of bus trips and two-wheeler trips (Zhang, 2004; Chatman, 2008). Network connectivity has a negative influence, may be because car travellers are bothered by the conflict at the intersections. Network entropy has a positive influence on trips by car, but it is insignificant for bus or two-wheeler trips. The presence of wide roads facilitates the movement of cars along with other vehicles. A denser road network shows a negative association with the number of bus or car trips. Road network will be denser in areas with intense commercial activity and other service facilities. The highly intense commercial activities induce heavy traffic on roads, which constrains the frequency of trips generated by the residents. This negative effect is in accordance with the literature (Crape and Crepeau, 1998). When including fractal dimension along with other network characteristics, fractal dimension shows negative influence on the number of trips by all modes.

7.2 Person-Kilometre of Travel by Different Modes

Table 6 shows the influence of network parameters on person-kilometres of travel by different modes.

Table 6. Model estimation results for person-km of travel by different modes

Variable	Bus Coeff. (t-value)	Car Coeff. (t-value)	Two-wheeler Coeff. (t-value)
exp (Gamma)	-4287** (-2.13)	-1984*** (-3.47)	-1986** (-2.24)
exp (Network Circuity)	3074*** (3.64)	182* (1.78)	1308*** (3.55)
exp (Network entropy)	-41.20 (-0.35)	3.66** (2.01)	-8.36 (-0.16)
Network Density^{b}	-0.010* (-1.86)	-0.34** (-2.32)	-0.003* (-1.77)
exp (Distance to CBD)	-0.010* (-1.66)	0.002 (0.41)	-0.018** (-2.31)
R-square	0.83	0.67	0.83
F-statistic	59.54	25.16	60.62

***Significant at 1% level; **Significant at 5% level; *Significant at 10% level.
b=5.17 for bus, 3.43 for car, 4.79 for two-wheeler

The gamma index, which reflects network connectivity, influences negatively and network circuity influences positively on the person-km of travel for all the modes. Network entropy shows a positive association with travel by car, but does not have a significant association with travel by bus or two-wheeler. People like to travel by car only when sufficiently wide roads are available. Otherwise, they choose to travel by two-wheeler or bus if available. A denser road network restricts travel, regardless of travel mode, due to intense activities and the resulting traffic jam. This is in line with the research evidence from Brownstone (2008), Vance and Hedel (2007). Modelling in terms of fractal dimension along with other network variables revealed that fractal dimension has a significant negative effect on person-km of travel by all modes. This is in line with the observations by Yoshihiko (2000).

7.3 Person-hour of travel by different modes

This section examines how the network aspects influence the person-hours of travel by different modes, and the results are shown in Table 7.

Table 7. Model estimation results for person-hr of travel by different modes

Variable	Bus Coeff. (t-value)	Car Coeff. (t-value)	Two-wheeler Coeff. (t-value)
exp (Gamma)	-404*** (-3.06)	-163*** (-3.63)	-184*** (-3.03)
exp (Network Circuity)	206*** (3.78)	21.21** (2.25)	67.21*** (2.7)
exp (Network entropy)	-3.03 (-0.41)	5.58*** (2.67)	0.03 (0.01)
Network Density^b	-0.027**(-2.24)	-0.99** (-2.53)	-0.010* (-1.72)
exp (Distance to CBD)	-0.002* (-1.85)	0.006 (0.19)	-0.001 (-0.51)
R-square	0.88	0.69	0.85
F-statistic	89.47	27.51	69.54

***Significant at 1% level; **Significant at 5% level; *Significant at 10% level.
b =3.81 for bus, 2.12 for car, 3.37 for two-wheeler

The availability of alternate routes due to improved road network connectivity enables the passengers to travel a lesser distance (and hence reduce the person-hour of travel), irrespective of the mode. Network circuity influences positively person-hours of travel by all the modes. Network entropy has a positive influence on person-hr of travel by car, but it is insignificant for travel by bus or two-wheeler. Network density has a negative influence on person-hour travel. For bus and two-wheeler trips, distance to the CBD is negatively associated with person-hours of travel, while it is insignificant for car trips. Models with fractal dimension showed that fractal dimension has a negative effect on person-hour travel by all modes.

8. Application

8.1 Comparison of Model Results with and without Fractal Dimension

A further intention of the study is to examine the influence of network fractal dimension on travel. The network aspect of the fractal dimension has been specifically highlighted because this aspect has not been included in any of the network travel studies. To compare the goodness of the models including fractal dimension with those without fractal dimension, R^2 values of the travel demand prediction models have been tabulated. Table 8 indicates the R^2 values for the models of travel by different modes.

On comparing the models with and without fractal dimension, R^2 is found to be comparatively high for the models without fractal dimension. This indicates the negligible influence of network fractal dimension on travel. Due to this, the fractal dimension cannot be highlighted as a network characteristic to be considered while designing the network.

Table 8. R^2 values for models with and without fractal dimension

Mode	Without fractal dimension			With fractal dimension		
	Number of trips	Person-km	Person-hr	Number of trips	Person-km	Person-hr
All trips	**0.89**	0.68	**0.88**	0.88	**0.83**	0.87
Bus	**0.88**	**0.87**	**0.88**	0.87	0.81	0.87
Car	**0.69**	**0.67**	**0.68**	0.67	0.64	0.65
Two wheeler	0.86	0.84	0.85	0.87	0.83	0.85

8.2 Elasticity of Travel

In this section, the idea is to examine how network aspects influence travel by different modes. By definition, elasticity is the percent change in travel that results from the unit percent change in the measure of the network. The individual elasticity estimates of the dependent and independent pairs demonstrating the travel demand and network characteristics are presented in Table 9. The idea is to obtain the variation of travel relative to network aspects. The further intention of the study is to examine the effect of network fractal dimension on travel demand. Considering the negligible influence of network fractal dimension on travel demand and the difficulty in expressing fractal dimension, the elasticity values for models with fractal dimension have not been tabulated.

Table 9. Elasticity of travel by different modes

Variable	Number of trips			Person-km			Person-hr		
	Bus	Car	Two-wheeler	Bus	Car	Two-wheeler	Bus	Car	Two-wheeler
Gamma	**0.31**	**-0.59**	**0.38**	**-0.44**	**-0.46**	**-0.24**	**-0.33**	**-0.37**	**-0.50**
Network Circuity	**-0.44**	**-0.35**	**-0.21**	**1.44**	**1.24**	**1.28**	**1.92**	**1.27**	**1.06**
Network Entropy	-0.001	0.02	0.10	0.01	0.004	-0.24	0.01	0.01	-0.001
Network Density	-0.03	-0.038	0.01	**-0.45**	-0.002	-0.09	**-2.33**	0.06	0.03
Distance to CBD	0.001	0.001	0.00	-0.03	0.11	-0.11	-0.04	0.01	0.011

The elasticity of the number of car trips to gamma is -0.59, which means that the car trips decrease by 0.59% due to 1% increase in gamma. The elasticity values suggest that travel is highly sensitive to gamma and network circuity, but less sensitive to other parameters such as network density, network entropy, or distance to CBD. Due to the population increase and urban development, controlling the number of trips seems quite difficult. However, we can think of reducing personal travel by improving the network design. Similarly, travel by car and two-wheeler can be kept to a minimum by increasing the connectivity and reducing the circuitous nature of the network. For instance, by increasing connectivity from 0.38 to 0.85, the person-kilometres of travel by car are reduced from 3030 km to 1279 km, resulting in a travel reduction of 0.58%. Again reducing network circuity from 2.06 to 1.02, travel by car reduces from 4841 km to 1964 km, causing 0.59% reduction in person-km.

Conclusion

The growing traffic in most cities is reducing mobility and causing related health issues. Henceforth, how to reduce travel has emerged as an increasingly important question. Many studies have analysed the relationship between the urban system and travel, but the results are not informative as the road network characteristics included in the studies were partial. As road network design has a key role in defining travel, network characteristics need to be studied in detail. Hence, the objective of the present study is to examine the influence of the road network on travel demand using data from Calicut city. Statistical models are prepared for examining the influence of network structure on travel demand. In the first phase, the influence of the road network on travel aspects of overall trips has been analysed. Subsequently, in the next phase, models for travel by different modes of car, bus, and two-wheeler were developed. The fractal dimension, being a network aspect that explains the details at multiple levels, has been included so as to examine its influence on travel.

The results indicate that travel demand differs according to network characteristics. With respect to overall trips, a well-connected road network causes residents to generate shorter trips. The analysis of trips by different modes indicates that the more connected and less circuitous the network is, the lower the person-kilometres of travel will be. A similar effect is visible for person-hours of travel as well. To sum up, the present study contributed to the literature by empirically establishing the fact that, the travel demand for the three modes of car, two-wheeler, and bus is significantly different. On analysing the influence of fractal dimension on travel, it is seen that fractal dimension has a significant effect on the number and length of trips. But considering the difficulty in evaluating the fractal dimension of a network and its irrelevance, the fractal dimension cannot be recommended as a factor to be included while designing the network.

The present study supports that transport network characteristics influences travel demand for the case of Calicut city and hence the same can be taken for reference of further research on how to reduce travel via transport network planning. Actually, it is the design of the road network which gives way to the improvement of the urban built-up structure and hence its pattern of development. The importance of transportation network planning as a tool to reduce travel has been highlighted in this study. Road network design is one of the potential strategies for managing travel demand and mitigating mobility issues.

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