Applicability of Centrality Measures to explain Vehicular flow in Colombo Municipal Council Area, Sri Lanka

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Abstract

Traffic congestion has become a major issue for all of the cities in the world. Sri Lanka also incurs 1.5% of GDP due to massive financial and man-hour loss due to traffic congestion. Thus, this sets the importance of understanding how development and design of future built environment influence travel demand and traffic flows. Traffic flow modeling enables us to envisage traffic flows in urban areas. Yet most of the current conventional models require the acquisition and analysis of large quantities of data such as the network topology, its traffic flow data, vehicle fleet composition, emission measurements and so on. Data acquisition is an expensive process that involves household surveys and automatic as well as semiautomatic measurements performed all over the network. Currently Sri Lanka and most of the Developing Countries follows these conventional Traffic Flow models, which identified as expensive affair and inefficient method. Therefore, predicting or understanding traffic flow has become an emerging challenge for Sri Lanka in this context.

Given this background this study focused on an emerging set of research literature that are employed in transport planning applications in developed countries. Those researches have based on network centrality parameters that revealed successful results in measuring traffic flow. Yet, all above studies based on developed countries and there are none or very limited applications with referring to the emerging cities in developing world where such research need the most. Therefore, this study looks at the applicability of centrality measures to access the traffic flows in Sri Lankan context. Accordingly, the objective of this research is to study the applicability of centrality measures to explain vehicular flow in Colombo municipal council area.

In this study we employed three centrality measures such as Degree, Betweenness and Closeness, which are borrowed from the domain of complex network analysis. Centrality values have been computed by axial map which was generated using motorable road network of the CMC. Then it calculated using UCL-Depth map and ArcGIS software applications. Generated Centrality values have been evaluated using actual traffic flow data along the CMC road network. Correlation analysis indicates that actual traffic flow values has a significant correlation with Degree (0.337 with significant at the 0.05 level), Betweenness (0.771 with significant at the 0.01 level) and Closeness (0.742 with significant at the 0.01 level) centrality measures. Multiple regression analysis results indicated that centrality measures have capabilities to explain over 78% of the variation of actual Traffic flow values. Therefore, the study suggests that Centrality Measures can serve as an alternative method to identify and predict traffic flow pattern of cities. Accordingly method developed in this study can be consider as robust and dynamic planning tool that will offer promise for spatial and transport planners to overcome emerging challenges and changing needs in the built environment.

Keywords: *Centrality Measures, Road Network and Traffic Flow*

Introduction

Sri Lanka incurs a massive financial and man-hour loss due to traffic congestion and it is 1.5% of GDP (Gross Domestic Product). It has identified that the poor city planning, inappropriate public transport facilities and insufficient traffic system are the main reasons for traffic congestion (Kumarage, 2011).

CMC (Colombo Municipal Council) area which is the commercial capital of Sri Lanka, has the highest vehicle density in Sri Lanka. 225,000 vehicles enter CMC daily and it creates a traffic congested environment in the peak hours of the day. Especially severe traffic congestion can be observed in entry points of the CMC area. It has found that the loss to Sri Lanka economy due to traffic congestions in Colombo city is Rs. 32 billion per year (Kumarage, 2011). It is 2% of the value of entire economic activities in Colombo city. The average speed of the vehicular flow in CMC is 22 km per hour. It is estimated that figure would drop to 15 km per hour, by 2031 (Kumarage 2011). Thus, this sets the need to look at how development and design of urban areas influence travel demand and traffic flows.

The vehicular flow studies in Sri Lanka starts after late nineteen sixties and since then number of studies carried out and transport models have been developed by different organizations. Most of the modeling procedures developed follows the conventional four-stage (Trip Generation, Trip Distribution, Mode Choice and Route assignment) sequential type of model structure. This has makes the traffic studies in Sri Lanka too quantitative or expensive and data-consuming tasks.
TRL report published in Transport Research Laboratory 2004 (cited in Cairns 2011) emphasized that the applications of traditional transport modeling which are commonly use in developing countries is an expensive affair and inefficient method. (Chiaradia 2006 cited in Paul, 2009).

Given this background this study focused on an emerging set of research literature those employed in transport planning applications in developed countries. Those researches have based on network centrality parameters which revealed successful results in measuring traffic flow.
Amongst, the work of Hillier and Hanson (1984); Hillier (1996) informed the development of the Space Syntax methodology, which has been applied in numerous cities world-wide. Multiple Centrality Measures (MCA) also identified as a crucial method to understand the structural properties of complex relational networks (Crucitti, Latora, and Porta, 2006).

Yet, all above studies based on developed countries and there are none or very limited applications with referring to the emerging cities in developing world where such research need the most. Further, many researches those are focused on cities in developed world do not directly applicable to cities in Asian Context (Munasinghe, 2007; Kishimoto, 2007; Hassan, 2008; Munshi, 2009). Therefore, this study looks at the applicability of centrality measures to access the Traffic flows in Sri Lankan context. The main objective of this research is to study the applicability of centrality measures to explain vehicular flow in Colombo MC, Area.

Centrality Measures

Centrality Measures is a fundamental concept in network analysis since its introduction in structural sociology (Bevalas, 1949). It had been frequently used in economic geography and city planning, to investigate the territorial relationships among communication flows, population, wealth and land-uses (Wilson, 2000).

Centrality in modern spatial analysis is strongly tied to graph theoretic measures of nodal relations in topological space. Erdos and Renyi (1960) defined centrality measures as analytical methods developed based on "Graph Theory"; centrality is relative importance of a vertex within the graph in terms of the degree of properties as number, distance, travel time, optimal path. According to the Freeman (1979) Centrality is a measure of the contribution of network position to the importance, influence, prominence of an actor in a network. Recent study done by Jayasinghe(2011) defines that centrality is an analytical method which has developed based on Graph Theory and it applies to compute levels of centrality in a network based on set of parameters.

Main Centrality Measures developed are as follows:

Degree centrality (Freeman, 1979) (Wasserman, 1994)

Degree centrality is the simplest form of vertex centrality. It is based on the idea that important vertices have a large number of ties to other vertices in the graph. The degree centralityof a node *i*in a graph is defined as

$$C_i^D = \frac{\sum_{j \in V} a_{i,j}}{n-1} = \frac{d_i}{n-1}$$

Where *di* is the degree of node *i*, i.e. the numberof nodes adjacent to *i*.

Closeness centrality (Freeman, 1979) (Sabidussi, 1966) (Wasserman, 1994)
Measures to which extent a vertex i is near to all the other nodes along the shortest paths Closeness centrality, and is defined as

$$C_i^C = \frac{n-1}{\sum_{\substack{j \in V \\ i \neq j}} \delta_{i,j}}$$

Where δi,j is the shortest path length between i and j.

Betweenness centrality (Freeman, 1979)
Edge Betweenness of an edge is defined as the number of shortest paths between pairs of vertices that pass through the given edge (Newman, 2002). Betweenness centrality is based on the idea that a vertex is central if it lies between many other vertex pairs, in the sense that it is traversed by many of the shortest paths connecting the vertex pairs. The Betweenness centrality of vertex i is where nj,k is the number of shortest paths between j and k.

$$C_i^B = \frac{1}{(n-1)(n-2)} \cdot \sum_{\substack{j,k \in V \\ j \neq k \neq i}} \frac{n_{j,k}(i)}{n_{j,k}}$$

nj,k (i) is the number of shortest paths between j and k that contain node i.

Straightness centrality (Latora, 2001)
Straightness centrality CS, originates from the idea that the efficiency in communication between two nodes i and j is equal to the inverse of the shortest path length δi,j. The straightness centrality of node iis defined as:

$$C_i^S = \frac{\sum_{\substack{j \in V \\ j \neq i}} \frac{\delta_{i,j}^{Eucl}}{\delta_{i,j}}}{n-1}$$

Where, Euclij !is the Euclidean distance between nodes i and j along a straight line.

This measure captures the extent to which the connecting route between nodes i and j deviates from the virtual straight route.

Information centrality(Latora, 2001)
Flow of information in a graph depends on how efficiently its vertices transfer information. The efficiency of communication between two vertices, say i and j, is inversely proportional to the shortest distance, δi,j, between them. The communication efficiency of the entire graph is defined as the average of efficiency values for all vertex pairs in the graph:

$$E(G) = \frac{\sum_{i \neq j \in V} \frac{1}{\delta_{i,j}}}{n \cdot (n-1)}.$$

However, when dealing with urban street patterns, centrality has been studied in relational Networks (Hillier 1984) where known as the dual representation (Jiang, Porta 2004) or information city network (Rosvall 2005), a city is transformed into a relational (topological) graph by mapping the streets into the graph nodes and the intersections between streets into edges between the nodes (Node Axis Diagram).

Freeman (1979) introduced axial map by converting roads into center lines and road intersections into nodes. This is more sensitive for centrality analysis as it considers metric distances for compute axis lines rather than the previous modal.

According to the axial map representation use by Hillier in space syntax, axial lines depict the line of visibility from the origin, or the eye level, to the point of maximum vision. Thus it termed as a visual network or graphical representation of the visibility lines. On that basis, centrality has considered as sensitive to topological distance. Further, an axial map of the city is defined as the least set of straight lines that pass through all the open space (Batty and Carvalho, 2003).

Centrality measures has been used to explain concepts related to network configuration, accessibility, integration, human behavior movements, land use in urban planning and transport planning studies.

Amongst, Betweenness centrality has been successfully applied to predict the Mobility patterns in Israel cities (Yaniv 2003). This study shows that considering travel time through links we can create a strong correlation between the traffic flow through nodes and their betweenness centrality. Also significantly higher correlation can be achived when clustering the roads into groups based on their types while also giving increased weight to data that is associated with certain hours. Using this method they have created "Mobility Oriented Betweeness Centrality" and its correlation value is approxiamatelyZ2 = 0.8. AisanKazerani (2001) examined Betweenness centrality with the time dependent travel demand. In this work, dynamic and temporal aspects of people's travel demand were studied by implementing a modified version of betweenness centrality. By approaching the hypothesis, the result showed a significant difference between traditional betweenness which was used to be utilized for traffic flow prediction and the so called modified betweenness centrality.

Literature identifies centrality as a key factor in shaping both urban space and urban life. Places that are perceived as central in respect to all others in the system of reference are assigned more value, are easier to reach and are more clearly conceptualized. This tends to attract more vehicle flows to central areas.

Most of the studies done and models developed in Sri Lanka in relation to Vehicular flow follow conventional methodologies. This can be simplified with the intervention of network analysis methods like centrality.

Method

The CMC is the largest local authority in Sri Lanka and one of the oldest in South Asia. Established in 1865, it has resident population of 637,865 (2001 census) and a floating population of nearly 400,000 (estimated). It covers an area of 37.31 sq km.

CMC area consists with 661.15 km long road network. It has four A class roads and two B class main roads. CMC area has the highest Vehicle density in the country. On an average, 250,000 vehicles, made up of 15,000 buses, 10,000 trucks and 225,000 private vehicles enter CMC daily. This creates severe traffic congestion in entry points of the CMC area (Colombo police Close Circuit Television (CCTV) unit).

Vehicular flow values have been extracted by the 2011 Traffic data base of Traffic Laboratory of University of Moratuwa (UOM) and Planning & Monitoring division of Road Development Authority (RDA). This includes 56 Traffic surveyed points along the CMC road network which has been surveyed for 16 hours starting from 6.00 a.m. to 10 p.m.

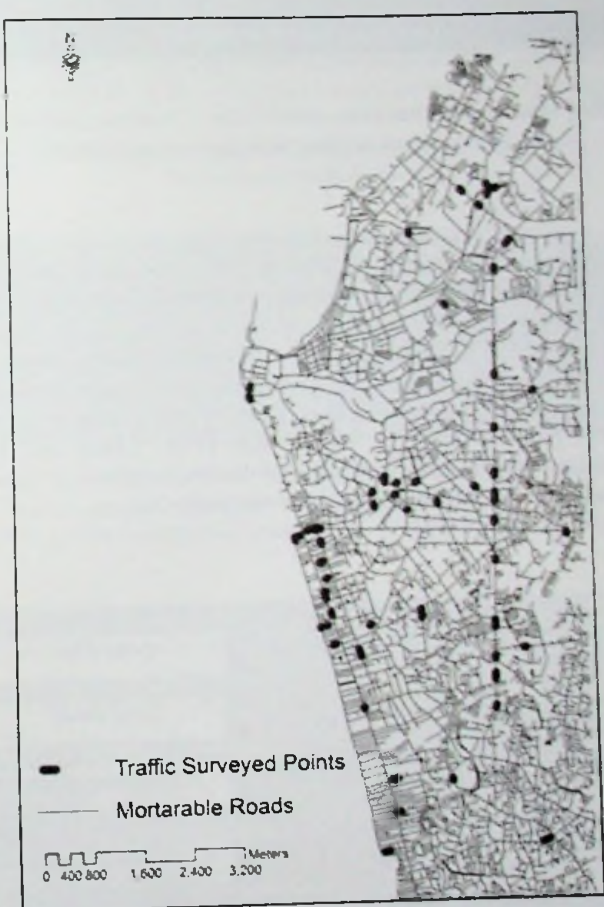

Figure1: Traffic surveyed points in CMC
Source: Author constructed

Conceptual framework

A series of empirical research studies dealing with built environment resulted strong co-relations between street centrality (configuration/accessibility) and the parameters as population & population density (Rosenbloom, 1996), employment (Cervero, 1996), land use (Cervero, 1996; Munasinghe, 2007; Min et al., 2006), land value (Min et al., 2007), and urban density (Peponis et al., 2007), spatial form of cities and different patterns of urban phenomenon (Abubakar and Aina, 2008; Hillier, 1998; Hillier and Iida, 2005; Sarma, 2006; Vaughan and Hillier, 2007)

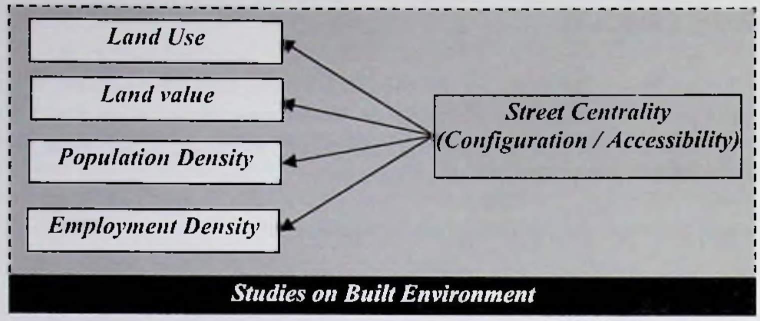

Figure 2:Identified relationship between urban form / land use with street centrality by research studies dealing with built environment

Source: Author constructed

Whilst, there was a series of studies emerged in the field of transport planning to find out alternatives to measures traffic volume. Earliest in 1977, Pushkarev and Zupan pointed out residential density and traffic volume are mutually correlating each other. Hendrickson (1986) examined the relationship between employment density and traffic volume in 25 USA metropolitan areas. Liu (1993), Kain and Liu (1995) established the relationship between regional development and ridership based on temporal development of Chicago transit system from 1976 to 1995. Studies on urban form and transit users Cervero (1993), Kain and Liu (1995), Nelson and Nygaard (1995), (Gomez-Ibanez, 1996), (TCRP, 1996), (Spillar and Rutherfod, 1998), (Chung, 1997), (Carane, 2000) found that residential density, employment density, land use mix and network connectivity as factors in relations to traffic volume. These findings can be summarized as below:

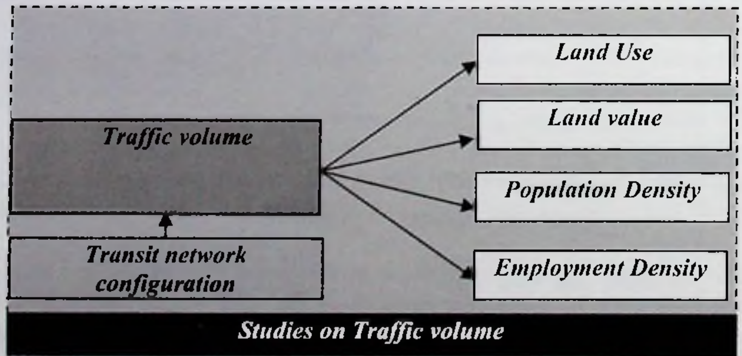

Figure 3: Identified relationship between urban form / land use with traffic volume by research studies dealing with transit demand

Source: Author constructed

Figure 3 illustrated the relationship of traffic volume to a set of attributes as land use, land value, population density and employment density. Figure 2 presented above illustrated the relationship of the same attributes to street centrality. Therefore, the non-transiting relationship of Figure 2 and Figure 3 can be illustrated in Figure 4.

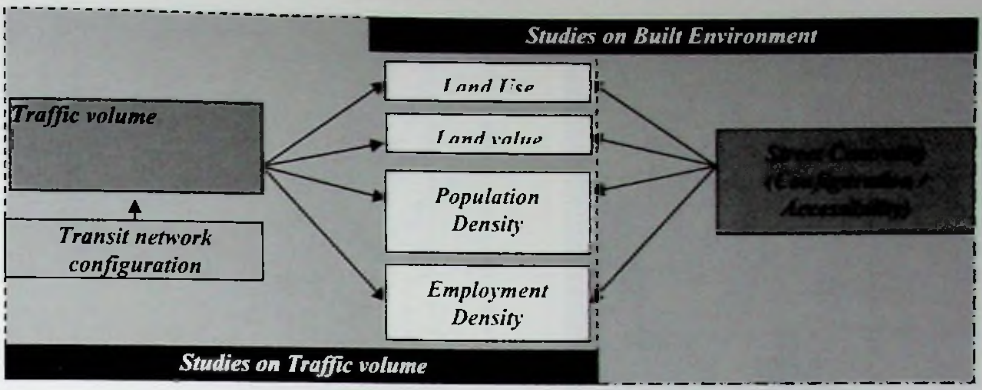

Figure 4: Non-transiting relationship between findings of built environment studies and transit demand *Source:* Author constructed based on relationship in figure 2 and 3

Based on that logic, this study argues that there is a direct relationship between street centrality and traffic volume.

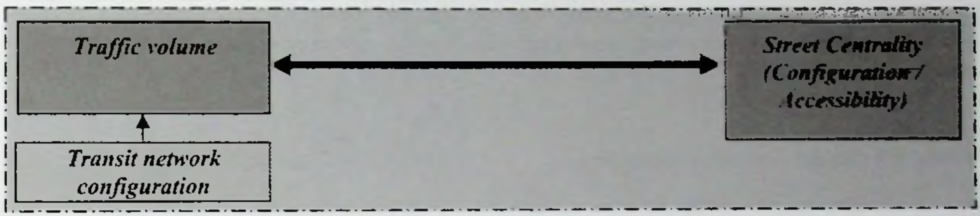

Figure 5: Research argument; Relationship between street centrality and transit network configuration with PT demand
Source: Author constructed based on relationship in figure 2, 3 and 4

Considering above, this research attempts to answer whether there is a relationship between traffic volume and network centrality and if so, to what extent?

Preparation of Axial line maps for CMC road network has been done by using Google earth satellite images and Arc GIS 9.3.

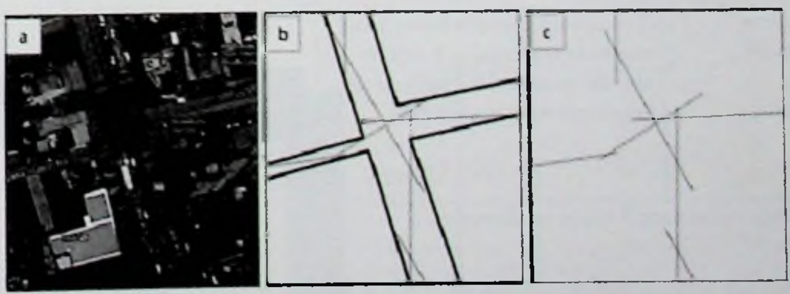

Figure 6: Preparation of axial lines
Notes: a. Google image, b. axial line preparation, c. axial map
Source: Author constructed

The vehicle flow count was considered all types of vehicles during the study. Most importantly one traffic data point consists of total number of vehicles travels to both directions in specific time period. This vehicular flow value then given for the respective axial line segment of the network.

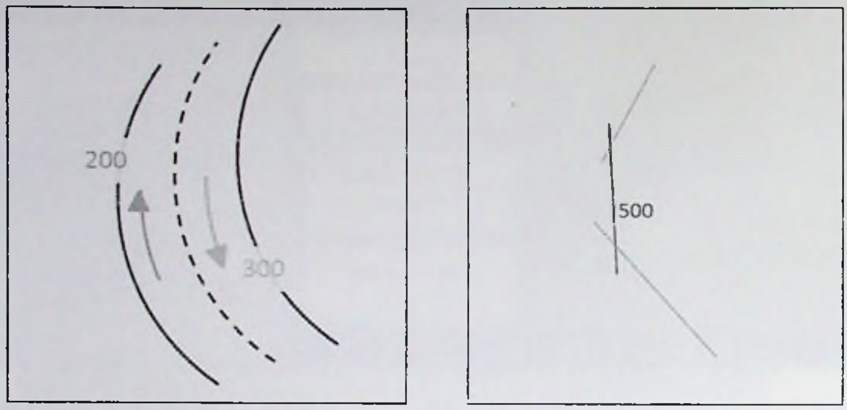

Figure 7: Computation of vehicular flow values
Source: Author constructed

Centrality values for CMC axial line network were calculated using UCL depth map 10. Only the following centrality measures were considered based on the applicability and the scope of the study.

Table 1: Selected centrality measures

Degree Centrality(DC)	To measure the extent that a road segment is connected to all segments in a network.	$C_i^D = \frac{\sum_{j\in V} a_{i,j}}{n-1} = \frac{d_i}{n-1}$
Closeness Centrality(CC)	To measures the extent that a road segment is near to all segments in the road network along the shortest paths.	[redacted]
Betweenness Centrality(BC)	To capture the idea that a road segment is central if it lies on the shortest paths that links all segments with each other.	[redacted]

Source: Author constructed based on literature

Analysis

Vehicular flow index

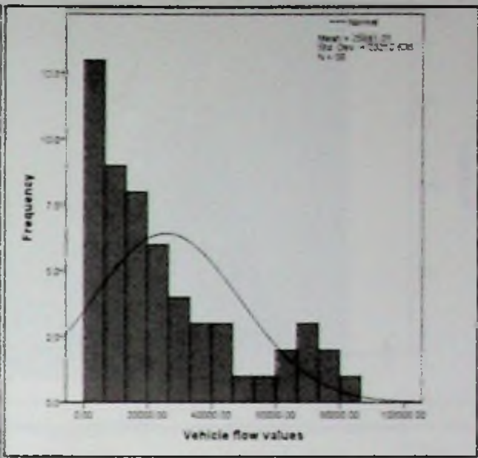

Figure 9: Histogram Vehicle flow values
Source: Author constructed

Figure 8: Vehicle flow values
Source: Author constructed

Histogram reveals that vehicular flow values show leftward skewness distribution and it has standard deviation of 23210.63 and Mean of 25841.01. The highest vehicular flow values recorded in baseline road and Gall road Traffic points.

Centrality Values of CMC

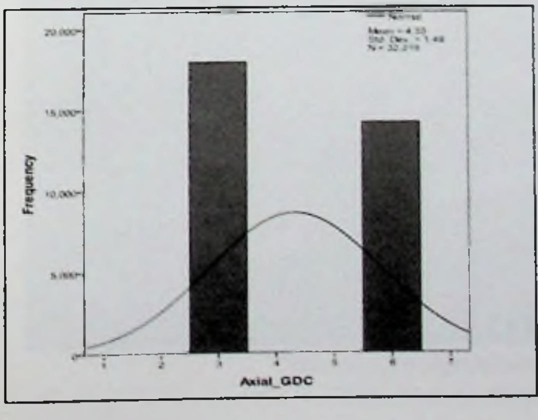

Figure 10: Histogram Degree Centrality
Source: Author constructed

Histogram shows that the large portion of the values of the Degree Centrality (DC) comes under value 3 and 6. It indicates that the majority of the road axial lines obtained Moderate or High DC values. High DC values can be observed in Road junctions. Other road segments have Moderate DC value.

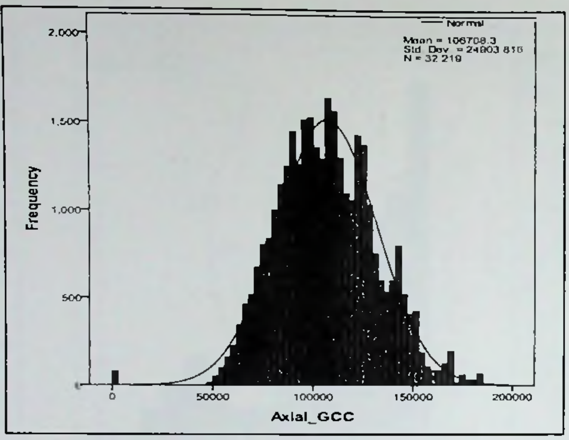

Figure 11: Histogram Closeness Centrality
Source: Author constructed

The histogram of Closeness Centrality (CC) shows that high CC scored in straight arteries. CC values have a mean of 106708.3 and standard deviation of 24903.81.

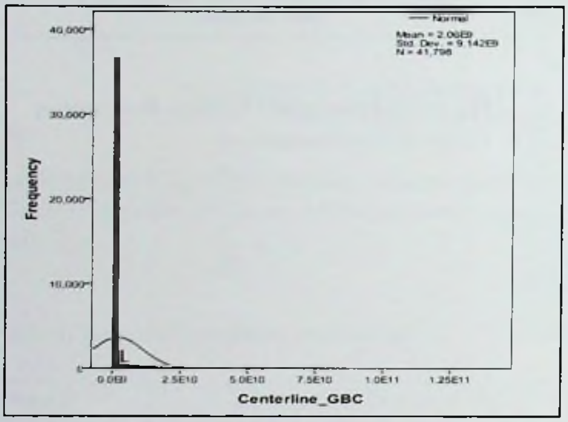

Figure 12: Histogram Betweenness Centrality
Source: Author constructed

Histogram of the Betweenness Centrality (BC) shows leftward skewness distribution. It reveals that mean BC value for axial lines is 3357223.03; Standard Deviation is 18111123.29. BC values show its highest in much straighter roads which links number of road intersections to each other.

Figure 13: GraphDegree Centrality
Source: Author constructed

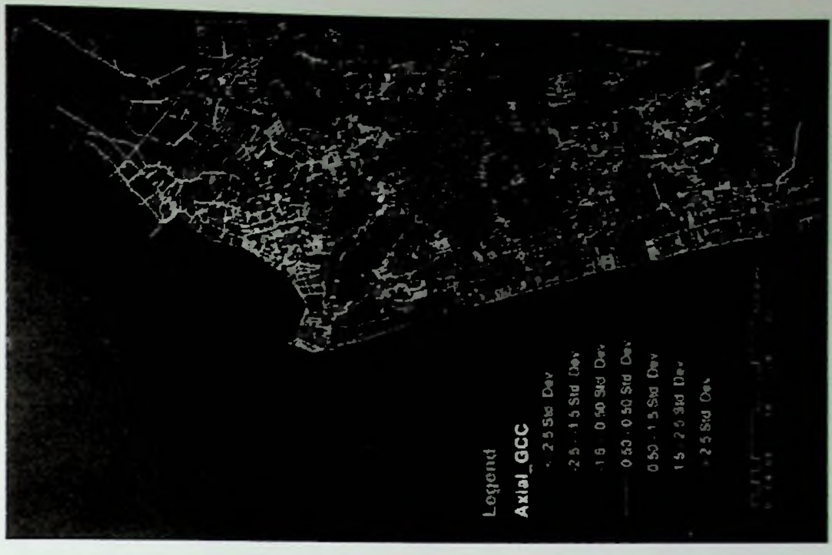

Figure 14: GraphCloseness Centrality
Source: Author constructed

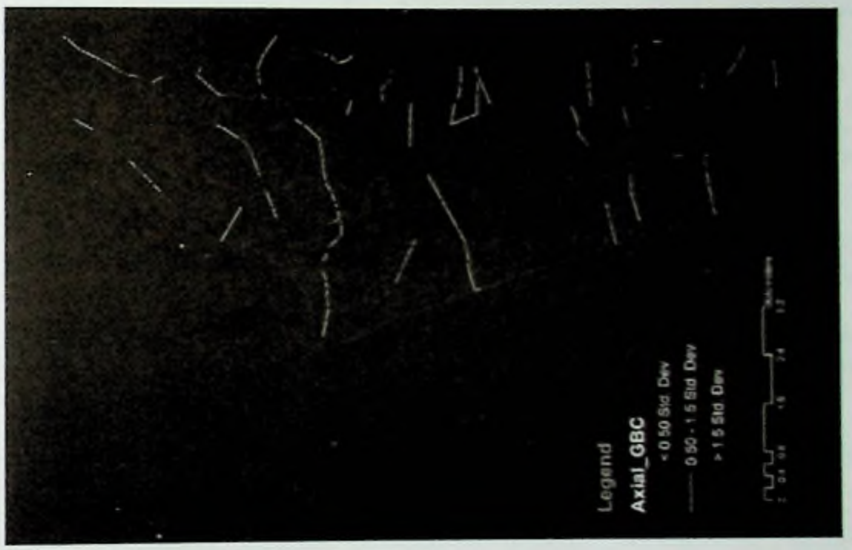

Figure 15: GraphBetweenness Centrality
Source: Author constructed

Correlation and Regression Analysis between Vehicular Flow and Centrality measures of Road Network

This test carried out with an understanding that vehicular flow of a road segment is directly proportionate to the network centrality values (DC, CC, BC). 'Bivariate Pearson correlation coefficient test' in SPSS (Statistical Package for Social Science, 18th version) software was used to perform this computation. Also this has been conducted for actual and log values for higher accuracy.

Table 2: Correlation value of axial lines - actual values

	Vehicular Flow		
	Pearson Correlation	Sig (2-tailed)	N
DC	0.266*	0.047	56
CC	0.557**	0.000	56
BC	0.655**	0.000	56

Source: Author Constructed
*Note:***Correlation is significant at the 0.01 level (2-tailed)
*Correlation is significant at the 0.05 level (2-tailed)

Table 1: Correlation value of axial lines - log values

	Ln_Vehicular Flow		
	Pearson Correlation	Sig (2-tailed)	N
Ln_DC	0.337*	0.011	56
Ln_CC	0.742**	0.000	56
Ln_BC	0.771**	0.000	56

Source: Author Constructed
*Note:***Correlation is significant at the 0.01 level (2-tailed)
*Correlation is significant at the 0.05 level (2-tailed)

Betweenness centrality and vehicular flow of road segments shows a highly significant coefficient of correlation (for actual values: r=0 .655, p < .01 & for natural log values: r= 0.771, p < .01) compare to other centrality values. Closeness centrality (for actual values: r= .557, p < .01 & for natural log values: r= .742, p < .01) reveals a significant coefficient of correlation with Vehicular flow. Degree centrality (for actual values: r= .266, p < .05 & for natural log values: r= .337, p < .05), shows a low significant coefficient of correlation with Vehicular flow. As correlations of those indicators are positive it can be concluded that centrality value directly proportionate to the vehicular flow.

It is observed that natural log values have higher coefficient of correlation value than actual value. It indicates that centrality value and Vehicular flow has 'Ln relationship' than 'liner relationship'.

Table 4: Ranking of centrality parameters based on correlation of coefficient

Centrality Parameter	For Actual Values		For Ln Values	
	R	Rank	R	Rank
DC	0.266*	4	0.337*	4
CC	0.557**	3	0.742**	2
BC	0.655**	2	0.771**	2

Source: Author Constructed

Multiple Regression Analysis

Forward linear regression is performed in this step. In forward entry method, variables in the block are added to the equation one at a time. At each step, the variable not in the equation with the smallest probability of F is entered if the value is smaller than probability of F-to-enter (the default value is 0.05). The response variable is the Vehicular flow (Pax). The predictor variables are Degree centrality (DC), Closeness centrality (CC) and Betweenness centrality (BC).

The study applied natural logarithms value for centrality and vehicular flow based on the correlation results. In that sense, a quasi-hedonic model explaining the vehicular flow values taking the following form is going to be created, tested, and analyzed.
Ln_Pax = *f*(Ln_DC, Ln_CC, Ln_BC)

Table 5: Coefficients - Regression models for axial line log values

Coefficients [a]												
Model	Unstandardized Coefficients		Standardized Coefficients	t	Sig.	95.0% Confidence Interval for B		Correlations			Collinearity Statistics	
	B	Std. Error	Beta			Lower Bound	Upper Bound	Zero-order	Partial	Part	Tolerance	VIF
1	.572	1.017		.562	.576	-1.468	2.611					
(Constant)	.416	.047	.717	8.894	.000	.322	.509	.717	.771	.717	1.000	1.000
Ln_BC												
2	-	5.897		-3.913	.000	-34.902	-11.246					
(Constant)	23.074	.055	.498	4.890	.000	.158	.379	.717	.558	.374	.563	1.775
Ln_BC	.268	.599	.413	4.057	.000	1.228	3.630	.742	.487	.310	.563	1.775
Ln_CC	2.429											
3	-	5.338		-4.702	.000	-35.810	-14.387					
(Constant)	25.098	.050	.431	4.614	.000	.131	.334	.771	.539	.318	.542	1.845
Ln_BC	.233	.539	.400	4.356	.000	1.268	3.433	.742	.517	.300	.562	1.778
Ln_CC	2.350	1.454	.263	3.659	.001	2.403	8.239	.474	.452	.252	.916	1.092
Ln_DC	5.321											
a. Dependent Variable: Ln_T												

Source: Author Constructed

Together the two predictor variables, Ln_BC and Ln_CC explain over 75% of the variance in Ln_Pax. Individually Ln_BC explain over 59% of the variance and Ln_CC explain over 11% in Ln_Pax. This finding is significant in that the assertion of network centrality being an effective explanatory or predictor variable for vehicular flow.

Ln_Pax = -23.074 + .268*Ln_BC + 2.429*Ln_CC

Table 6: Coefficients - Regression models for axial line log values

Model Summary [c]										
Mode l	R	R Square	Adjusted R Square	Std. Error of the Estimate	Change Statistics					Durbin-Watson
					R Square change	F Change	df1	df2	Sig. F Change	
1	.771 [a]	.594	.587	.88788	.594	79.095	1	54	.000	
2	.831 [b]	.690	.679	.78287	.096	16.459	1	53	.000	
3	.868 [c]	.754	.740	.70483	.063	13.386	1	52	.001	1.090
a. Predictors: (Constant), Ln_BC										
b. Predictors: (Constant), Ln_BC, Ln_CC										
c. Predictors: (Constant), Ln_BC, Ln_CC, Ln_DC										
c. Dependent Variable: Ln_T										

Source: Author Constructed

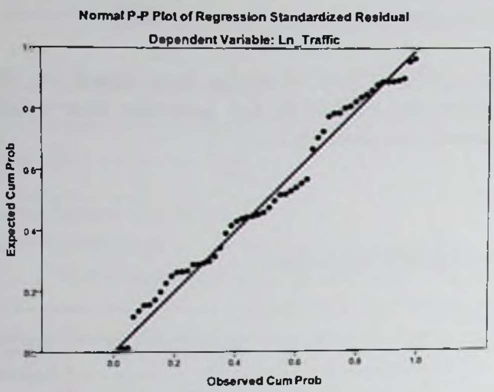

Figure 16: Diagnostic plots for the final regression model for axial lines
Source: Author constructed

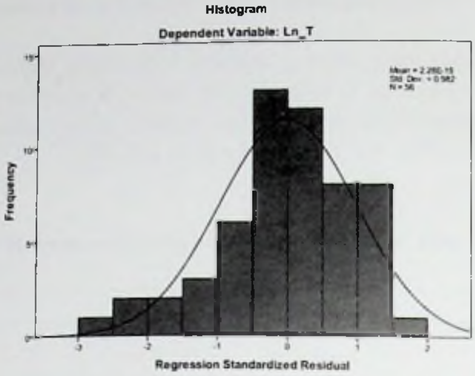

Figure 17: Histogram for the final regression model for axial lines
Source: Author constructed

Results indicate that centrality values of axial lines explain vehicular flow to a greater accuracy level. This study proves that the level of Betweenness or the extent that road segment locate intermediary to other road segments is the key factor (65%) on volume of traffic flow. Closeness of the road segment to other road segments also has 55% influences on volume of traffic flow.

Conclusion

This study is carried out in a locality where there are very limited research attempts on vehicular flow. Further, the current practices in this nature are hampered by methodological, technical, financial and information availability issues. Therefore, this research pays attention to a series of recent, popular traffic demand studies based on centrality measures which bring good results in measuring vehicular flow.

The results of this study show that centrality measures have a significant correlation with vehicular flow values. As aimed in objective this research, Degree, Closeness and Betweenness centrality were identified as appropriate centrality parameters that can use to measure network centrality of road network. Amongst, Betweenness centrality (65%) resulted significant relationship with traffic flow and Closeness centrality (35%) too had significant relationship with traffic volume.

For Actual Values = 0.655
For Ln Values = 0.771
Correlation is significant at the 0.01 level (2-tailed)

Finally this study concludes that centrality measures and method developed in this research is useful method to explain the traffic volume of road segment that could otherwise be very difficult to extract and to analyze from the conventional approaches. Further, study suggested that method developed in this research can be used as a planning and policy tool to identify the impact from road augmentation, new road constrictions to traffic volume of existing road network; to identify the impact from proposed land use plans to traffic volume of existing road network.

Though this research successfully achieved desired objectives, this can be developed into much advance analysis by conducting further studies in relation to network centrality and temporal change in traffic volume changes (peak – off peak). And the same analysis can be tested at some other areas to validate the applicability.

The methods developed in this research offers promise for spatial and transport planning applications in Sri Lankan context that it is urgently called for. This research has contributed to with a robust, dynamic planning tool that will guide spatial and transport planners in justifying their planning decisions in designing transportation or urban development strategies in Sri Lankan cities. Further, this is a positive contribution to emerging literature on spatial applications of network centrality parameters in Asian cities.

Reference

Amal Kumarage, "Massive Rs 32 bln loss due to traffic congestion:Transport expert", *The Sunday Times*, http://sundaytimes.lk/110313/BusinessTimes/bt03.html

Albert, C.A.; Scellato, S.; Latora, V, and Porta, S., (1999) Structural properties of planar graphs of urban street patterns [online]. Physical Review E 73, 066107 (2006).Available from :www.cl.cam.ac.uk/~ss824/papers/street_patterns.pdf.

Batty, M. and Carvalho, R., (2003) A rigorous definition of axial lines: ridges on isovist fields [online]. UCL Working Paper Series, 6. Available form: arxiv.org/pdf/cs/0311012

Bavelas, A.,Smith S, 1948: Some Problems of Organizational Change. Journal of Social Issues, 4: 48-52.

Cairns, S., (2011) Accessing Car [online]. Available from: www.liftshare.com/business/pdfs/RAC_142.pdf

Chiaradia, A.; Moreau, E. and Raford, N., (2006) Con-gurational Exploration of Public Transport Movement Networks: A Case Study, The London Underground. [online] . Available from: www.springerlink.com/index/m6x1mt0325l61410.pdf

Crucittia, P.; Latorab, V.; and Marchioric, M., (2004) A Topological analysis of the Italian electric power grid [online]. Italy, Universita di Venezia. Available from: http://www.sciencedirect.com

Erdos, R.; Renyi, R. and Chen.D., (1960) Measuring Sprawl and Its Impacts, Smart Growth America [online]. Available from : www.smartgrowthamerica.org.

Freeman, L. C., (1979) Centrality in social networks: Conceptual clarification. Social Networks [online]. 1(3), 215-239. Available from: www.socialnetworks.org

Hassan, A. and Hoque, M.D., (2008) Simplified Travel Demand Modeling Framework: in the Context of a Developing Country City [online]. Available from: www.codatu.org/english/conferences/codatu13/PROGRAMME.pdf

Hillier, B., (1996) Space is the machine, [online]. Cambridge University Press, Cambridge. Available from: www.space-machine.com

Harris, B., (2001) Accessibility: Concepts and Applications [online]. Journal of Transportation and Statistics, Bureau of Transport Statistics, Vol. 4, pp. 15-30. Available from: www.bts.gov/publications/journal_of_transportation_and_statistics/volume_04number 23/ paper 02/index.html.

Hillier B, Hanson J, 1984 *The Social Logic of Space* (Cambridge University Press, Cambridge)

Hoogendoorn, 2009.Discrete flow model for dynamic network loading.Ph.D.thesis, Départementd'informatiqueet de rechercheopérationnelle, Université de Montréal, Montréal, Quebec, Canada.

Jayasinghe A.B, Munshi T.(2011) An application of "Centrality Measures" to identify the relationship between Network Centrality & the Transit Demand at Public Transit Stops; A Case of Ahmedabad City, India, CEPT University press, Ahmedabad, India

Kazerani, A.; &Winter, S.; (2009) Can Betweenness Centrality Explain Traffic Flow? [online]. 12th AGILE International Conference on GIS 2009. Available from: www.ikg.uni-hannover.de/agile/fileadmin/agile/paper/111.pdf

Kishimoto, T.; Kawasaki, S.; Nagata, N. and Tanaka, R., (2007) Optimal Location of Route and Stops of Public Transportation [online].6th International Space Syntax Symposium, İstanbul, 2007. Available from: www.spacesyntaxistanbul.itu.edu.tr/papers%5Clongpapers%5C075%20- %20Kishimoto %20Kawasaki%20Nagata%20Tanaka.pdf

Latora V, Marchiori M. 2001. Efficient behavior of small-world networks.Phys Rev Lett 87:198701

Munasinghe, J. and Bandara, A., (2007) Evolution of a City: A Space Syntax Approach to Explain the Spatial Dynamics of Colombo. Conference Paper presented at APSA Conference, Colombo, Sri Lanka

Munshi, T.; Zuidgeest, M. and Brussel, M., (2009) Geo-Spatial Urban Form – Travel Behviour Model for the City of Ahmedabad, India. Conference paper presenter at APSA Conference, Ahmedaba, India

Munshi, T., (2003) Planning Public Transport of Ahmedabad City in India, In UPLA, ITC, Enschede

Sabidussi, N.; (1966) Urban planning, information technology and cyberspace [online]. Journal of Urban Technology 7(2):105-126. Available from: www.cardiff.ac.uk/cplan/.../s.../shiode-narushige-dr-publication.html

Shiode, N.; (2000) Urban planning, information technology and cyberspace [online]. Journal of Urban Technology 7(2):105-126. Available from: www.cardiff.ac.uk/cplan/.../s.../shiode-narushige-dr-publication.html [Accessed 11th December 2010] Shiode, N.; and Okabe, A.; (2001) A computational method for optimizing the shape and location of a polygon on a plane [online]. International Transactions in Operational Research 8(5): 547-559. Available from: www.cardiff.ac.uk/cplan/.../s.../shiode-narushige-dr-publication.html

Transport Research Center (2007)-Managing urban traffic congestion(2007), ECMT Report(online), ECMT publications, Available from: www.internationaltransportforum.org/Pub/pdf/07Congestion.pdf

Wasserman, R., (1994) On the metric, topological and functional structures of urban networks. [online]. Physica A 387, 2120–21. Available from: www2.mta.ac.il/ ~rwagner/publications/urban%20networks.