Network Centrality Analysis of Public Transport Systems: Developing a Strategic Planning Tool to Assess Passenger Attraction

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1. Introduction

Cities in developing countries have recently witnessed a rapid economic growth and urban sprawl, which is resulting in an accelerated increase of vehicular movements in urban areas. This situation raises the immediate necessity of an effective public transport (PT) system in developing countries. However, while some cities have managed to shift a significant number of car journeys onto rail and buses, many are struggling despite the considerable effort to make PT systems more attractive [1]. In formulating strategies to develop PT systems, passenger attraction to the PT system has often taken a back seat; perhaps due to the lack of adequately robust methods and data availability. Thus there is a need to develop alternative methods of evaluate the passenger attraction to PT systems; methods that can be relied upon in the face of data, cost and technical know-how constraints experienced by many agencies in developing countries. In such a background, this study attempts to explore the potential of 'Network Centrality Analysis' as an alternative method to estimate transit volume in PT stations.

The work of Hillier et al. on 'Space Syntax' has provided the initial development of the centrality analysis about road networks [2]. The analysis of centrality of transits networks, in order to capture accessibility and explain the passenger demand in cities, has received increasing attention in recent years [2],[3],[4],[5].

2. Methodology

The study has conceptualised the level of passenger attraction to a transit station as depending on

- Accessibility to the transit station from origin/destination point (residential or employment area) of the trip maker, and
- Movement opportunities from the transit station across the PT network.

Accordingly, the study employed closeness centrality (CC) to measure the level of accessibility to a station from surrounding areas via a set of road segments; and betweenness centrality (BC) to measure the level of movement opportunities from a station to all other stations within the PT network. The study developed two centrality indices. Table 1 summarises the key features of those indices.

Table 3: Key features of the proposed centrality indices

Index	Accessibility(A)	Movement opportunities(M)
Centrality measure	CC [2]	BC [2]
Network	Road network	PT network
Node	Station/Road intersection	Station
Link	Road segment	Transit line
Link weighted	1/Topological distance	Frequency of transit service/Average travel time
Impact radii	R=.5km,1.5km,2.5km,5km, 7.5km,10km,15km	R=r (Whole network)

The case studies were performed in Ahmedabad Municipal Council Area (AMC), India (Bus network-2009 and BRTs network-2010) and Sri Lanka (Railway network-2010).

3. Results

The study tested the correlation between actual passenger volume and centrality values (Table 2).

Table 4: Summary of the correlation coefficient (r) values

	Centrality	
PT Network	**CC**	**BC**
Bus-AMC (n=1398)	0.61**(R=1.5km) 0.41**(R=2.5km) 0.27**(R=5km)	0.92**(R=r)
BRTs-AMC (n=38)	0.73**(R=5km) 0.71**(R=1.5km) 0.68**(R=2.5km)	0.81**(R=r)
Railway-SL (n=130)	0.79**(R=5km) 0.56**(R=7.5km) 0.34**(R=2.5km)	0.62**(R=r)

**Correlation is significant at the 0.01 leve

Figure 1 illustrates the spatial distribution of passenger volume and centrality values.

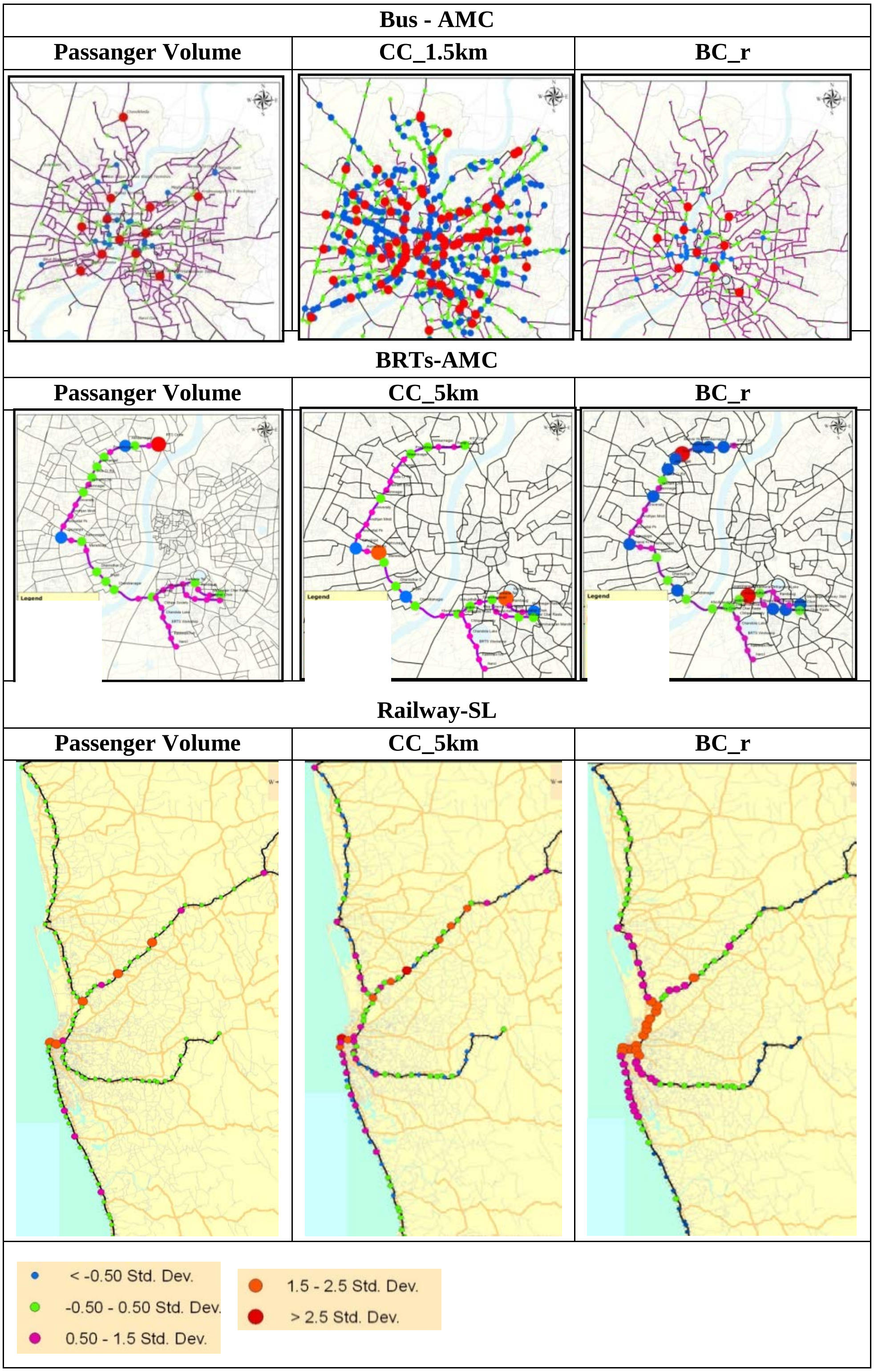

Figure 1: Spatial distribution of passenger volumes and centrality values

Linear regression analysis was performed to investigate the relationship of passenger volume with the centrality values. Regression results indicated that passenger volume at a given station can be estimated by centrality values (Table 3).

Table 3: Summary of regression analysis

PT network	R-Squared	Variables	Beta	Sig.	Correlations			VIF
					Zero-order	Partial	Part	
Bus-AMC	0.928	Constant		.000				
		BC_r	.618	.000	.92	.79	.39	2.45
		CC_2.5km	.424	.000	.61	.52	.27	2.45
BRTs-AMC	0.871	Constant		.000				
		BC_r	.615	.000	.81	.74	.54	1.28
		CC_5km	.393	.000	.73	.57	.34	1.28
Railway-SL	0.814	Constant		.000				
		CC_5km	.639	.000	.79	.73	.57	1.25
		BC_r	.335	.000	.62	.49	.29	1.25

Partial correlation values indicated that BC_r (i.e. movement opportunities from the transit station across the PT network) revealed 63% influence while CC_2.5km (i.e. accessibility to the station from 2.5km radius area) revealed 27% influence over passenger attraction to bus stations. In BRTs stations, BC_r has recorded 62% and CC_5km has recorded 32% influence. For railway stations, CC_5km has revealed 53% influence while BC_r has revealed 24% influence over passenger attraction to train stations.

4. Conclusion and Recommendation

The objective of this study was to explore the potential of 'Network Centrality Analysis' method to estimate passenger attraction to PT stations. The result indicated that the network centrality is a useful indicator for estimating passenger volume at stations. The recorded R^2 values are on par with international standards (i.e. Federal Highway Administration, USA; R^2>0.85) and with the results of previous works on estimating transit passenger volume using 'EMME' multi-step travel demand modelling in Ahmadabad (R^2>0.87). Further, the findings emphasised the ability of network centrality to account for passengers' attraction to stations in terms of accessibility to stations and movement opportunities.

This method is highly recommended for assignments conducted in developing countries due to the following key strengths.

- Less data consuming: Derived intrinsically from network centrality measures. Hence, does not demand an extensive land use and O-D trip data

- Technically simple: Computed using a network analysis tool typically available in the GIS environment.

Therefore, the method can be utilised as a strategic planning tool in identifying strategic interventions to attract more passengers to PT stations or to analyse the attractiveness of a proposed PT network. However, at this stage, the proposed centrality based method lacks the ability to model temporal changes (peak and off-peak) and future predictions (considering socio economic growth). The authors are working to overcome these limitations in their forthcoming work.

5. References

[1] Ahmad S. and de Oliveira, J. A. P. (2016). Determinants of urban mobility in India: Lessons for promoting sustainable and inclusive urban transportation in developing countries, Transport Policy, 50, 106-114.

[2] Scheurer, J., Curtis, C. and Porta, S. (2007). Spatial Network Analysis of Public Transport Systems: Developing a Strategic Planning Tool to Assess the Congruence of Movement and Urban Structure in Australian Cities. Perth: Australasian Centre for the Governance and Management of Urban Transport.

[3] Derrible, S. (2012). Network Centrality of Metro Systems, PLoS ONE, 7(7), e40575.

[4] Huang, Z. and Liu, X. (2014). A hierarchical approach to optimizing bus stop distribution in large and fast developing cities. ISPRS International Journal of Geo-Information, 3(2), 554-564.

[5] Dimitrov S. D. and Ceder, A. A. (2016). A method of examining the structure and topological properties of public-transport networks, Physica A: Statistical Mechanics and its Applications, 451, 373-387.

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