Network Centrality Assessment (NCA) for Simulate Traffic Volume: A Strategic Planning and Investment Tool for Developing Countries

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This paper introduces a novel traffic simulation method (i.e. Network Centrality Assessment – NCA) which is pragmatic for developing countries and application possibilities as a strategic planning and investment tool. The proposed method developed based on centrality concept while incorporating the notion O-D trips, which is described in multi-step demand modeling framework. The most notably proposed method does not require either detailed database on land use and O-D trip data as it need for multi-step demand modeling framework. Further, we have demonstrated capabilities of NCA as a strategic planning and investment tool based on case studies with acceptable level of accuracy. Accordingly, this study suggests that NCA which is currently not in practice has a potential to be utilized as a strategic planning and investment tool in urban areas in developing countries, especially because NCA can efficiently work under data, cost and technical know-how constrained situations.

Key Words : *Traffic Simulation, Investment Tool, Centrality, Developing Countries, Data Constrains,*

1. INTRODUCTION

Urban areas in most of the developing countries, particularly in South Asia, have faced major challenges in traffic management and control in recent decades. Cities in those countries have recently been witnessed a rapid economic growth and urban sprawl, resulting an accelerated increase of vehicle movements which create several problems such as traffic congestion, road accidents and air pollutions.

Therefore, it is important to formulate urban transport strategies and identify strategic transportation infrastructure projects for investment, before reaching the critical situation [1]. However, most of the transport planning efforts in developing countries have been based on the multi-step demand (4 stage) modeling process [2] which is difficult to be adopted for forecasting traffic in developing countries [3]. The difficulties of adopting conventional multi-step modeling in developing countries includes inadequate database for planning especially on land-uses and O-D trip data, inadequate technical expertise in planning and implementing agencies, lack of funds to collect data and use sophisticated software applications [4) - 5)].

We have developed a new method based on graph theory and centrality to simulate traffic volume, which can effectively works to overcome the above-mentioned difficulties. Accordingly, this paper introduces the developed method, i.e. 'Network Centrality Assessment'-NCA, and application possibilities based on five case studies carried out in Sri Lanka and India.

2. NETWORK CENTRALITY ASSESSMENT (NCA)

NCA is an analytical method that is developed based on the graph theory and applies to compute levels of centrality in a network based on a set of parameters. NCA is supported by the three analytical frameworks i.e. 'Space Syntax' [6]; 'Multiple Centrality Assessment'-MCA [7]; and 'Spatial Design Network Analysts'-sDNA- [8] and three key theories i.e. 'cities as movement economics' [6]; 'cognitive wayfinding behavior of human' [9] and 'allocentric and egocentric human spatial representation and movements behaviors' [10]. The traffic demand estimation by NCA is comprised with four key steps; i. preparation of graph, ii. computation of centrality, iii. calibration and iv. simulation (refer **Fig.1**).

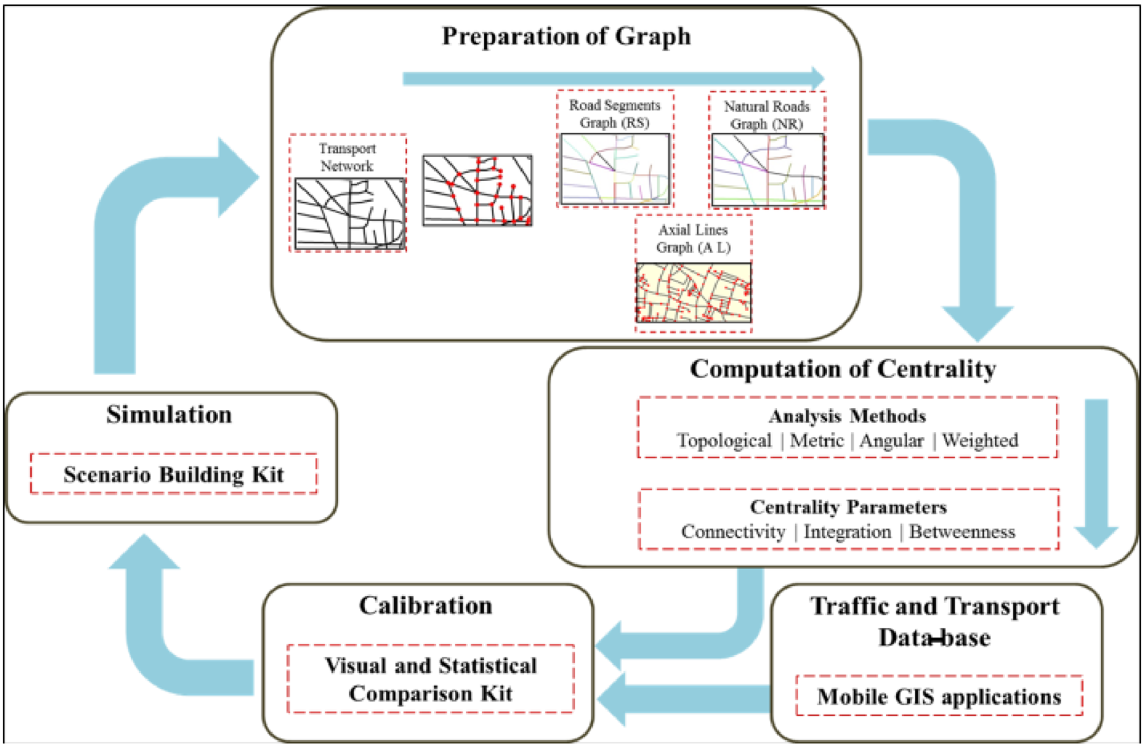

Fig.1 Network Centrality Assessment (NCA)

Accordingly, the first step is translating the real network into a graph that converts the actual road network into a graph consists of nodes and links. NCA use three kinds of graphs which, are 'Axial-Lines' [11], 'Road-Segments' [12] and 'Natural-Roads' [13]. The second step is computing centrality. Centrality is usually quantified based on the topological distance (i.e. topological distance-TD, geo-metric distance-GMD) [14)-15)-16)-17)]. Our approach not only utilized topological distance to quantify centrality but also metric distance (MD), travel time (Tt), road type (Ty), road capacity (Cp) and their combinations as link costs. NCA consists of multiple centrality parameters i.e. betweenness centrality (BCC) [18], global closeness centrality (GCC) [15], local closeness centrality (LCC) [16] and connectivity centrality (CC) [16]. In the third step NCA examines the power law distribution of centrality values based on spatial statistical analysis. Finally, it calibrates simulation model based on actual data and validate the traffic demand forecasting formulae. We have developed and validated such simulation formulae for South-Asian cities based on our case studies in Sri Lanka and India (refer **Table 1**).

Table 1 Simulation formulae

Purpose	Formula
Predicting Annual Average Daily Traffic (AADT) volume	AADT $= f(LCC_{MD\&Ty} * GCC_{GMD\&Ty} * BCC_{GMD\&Ty})$
Transit demand of bus stop (Pax)	Pax $= f(LCC_{TD} * GCC_{TD\&Tt} * BCC_{TD\&Tt})$
Trip Attraction (TA)	TA $= f(LCC_{MD\&Ty} * GCC_{GMD\&Ty})$

The proposed simulation framework (i.e. NCA) is developed by incorporating mobility characteristics and route choice characteristics, which are described in the notion of origin-destination (O-D) in the multi-step demand modeling framework (MSM) in to the notion of 'Spacey Syntax' (SS), which is introduced by Hillier [6] (refer **Table 2** for details).

Table-1: Incorporating the notion of origin-destination (O-D) in multi-step modeling (MSM) into 'Space Syntax' (SS)

Traffic attributes	The Notion of O-D trips in MSM	The Notion of Space Syntax (SS)	The Proposed Framework (NCA)
Movements	▪ Determined by the gravitational attraction between TAZs which is driven by land use and travel cost ▪ Travelers move between origin (home) and destination (workplace)	▪ Determined by the structure of the urban grid itself rather than by the presence of specific attractors or magnets ▪ Travelers move in line reading space based on landmarks and connections between landmarks	▪ Predominately determined by the structure of the urban grid while accounting the influence of land uses ▪ Travelers move between origin and destinations reading their route based on road segments, natural roads and nodes
Volume of trip attraction	▪ Determined by the land uses	▪ Determined by the level of integration	▪ Predominately determined by the level of integration global and local closeness) while taking into account the influence of special trip attraction land uses (i.e. Education, Industries)
Volume of trip generation	▪ Determined by the household socio-economic conditions	▪ NA	▪ Determined by the residential land uses and level of integration global and local closeness)
Selection of destination	▪ Determined by the available opportunities (i.e. employment, commercial activities, education etc…)	▪ Determined by the closeness. Recognized reciprocal relationship between available opportunities and level of integration in streets	▪ Determined by the available opportunities. Recognized reciprocal relationship between available opportunities and level of integration in streets
Volume of trip distribution	▪ Gravitation attraction which is tempered by the travel cost (i.e. distance) is the primary determinant	▪ Configuration of the street network is the primary determinant	▪ Gravitation attraction which is tempered by the centrality and centralization
Route choice	▪ Individual travelers select the best route that maximizes their utility by comparing all possible alternatives. Utility function is a complex measure comprised of many factors such as length, travel time, traffic congestion, road condition etc	▪ Individual travelers ▪ actually distance is conceptualized as a product of turns (topological) and angle changes (geo-metric)	▪ Individual travelers conceptualized distance; ▪ In global level: as a product of angle changes (geo-metric) and road type ▪ In local level: as a product of metric distance and road type
Traffic volume of a roadway location	▪ Consider both to-movements and through-movements	▪ Consider any to-movement bias towards integrated locations will also have an effect on through-movement	▪ Consider both to-movement (which is significantly influenced by the level of global and local integration of the location global and local closeness) and through-movement (which is significantly influenced by the level of betweenness of the location)

3. NCA AS A STRATEGIC PLANNING AND INVESTMENT TOOL

NCA is highly recommended to be employed in predicting traffic over the conventional multi-step demand models because it requires relatively a little amount of data (refer **Table 3**), is easy to calculate, and is intuitive .

Table 3 Required data and simulation accuracy

Mo del	Purpose & (Variable/s used)	Required Data	Pre-dicta-bility	MdAPE
1	Simulate AADT (BCC_{GMD})	Road Net-wokr	50.94%	58.21
2	Simulate AADT ($BCC_{GMD,}$ $GCC_{GMD,}$ $LCC_{MD)}$	- Do -	67.01%	43.24
3	Simulate AADT ($BCC_{GMD\&Ty}$)	Road Net-work and road type	69.55%	46.43
4	Simulate AADT ($BCC_{GMD\&Ty,}$ $GCC_{GMD\&Ty,}$ $LCC_{MD\&Ty}$)	- Do -	88.91%	26.07
5	Simulate transit de-mand of bus stops (LCC_{TD} * $GCC_{TD\&Tt}$ * $BCC_{TD\&Tt}$)	Road net-work and type; transit network, travel time and fre-quency	92.64%	17.34
6	Simulate transit de-mand of BRTs stops (LCC_{TD} * $GCC_{TD\&Tt}$ * $BCC_{TD\&Tt}$)	Road net-work and type; transit network, travel time and fre-quency	79.18%	28.34
7	Simulate trip attraction ($LCC_{MD\&Ty}$* $GCC_{GMD\&Ty}$)	Road Net-work and road type	79.32%	-

Note: MdAPE Median Absolutely Percentage Error

Utilizing the centrality variables are especially advantageous because, it is,

(1) derived intrinsically through network analysis, hence, land-use and extensive O-D trip data are not required
(2) integrates travel demand to the transportation system characteristics (i.e road type, travel time) as well as human cognitive behavior on distance (i.e. topological and geo-metric distance)
(3) exhibits better predictability (refer **Table 3**) at the aggregated level (i.e. Traffic Analysis Zones) as well as disaggregated level (i.e. road segments, transits stops)

Therefore, NCA can be used as an effective tool to estimate traffic volumes (i.e. AADT, Passenger volumes) particularly in small and medium-sized cities of developing countries where extensive data collection surveys and multi-step demand models are constrained to afford (refer **Fig.2**).

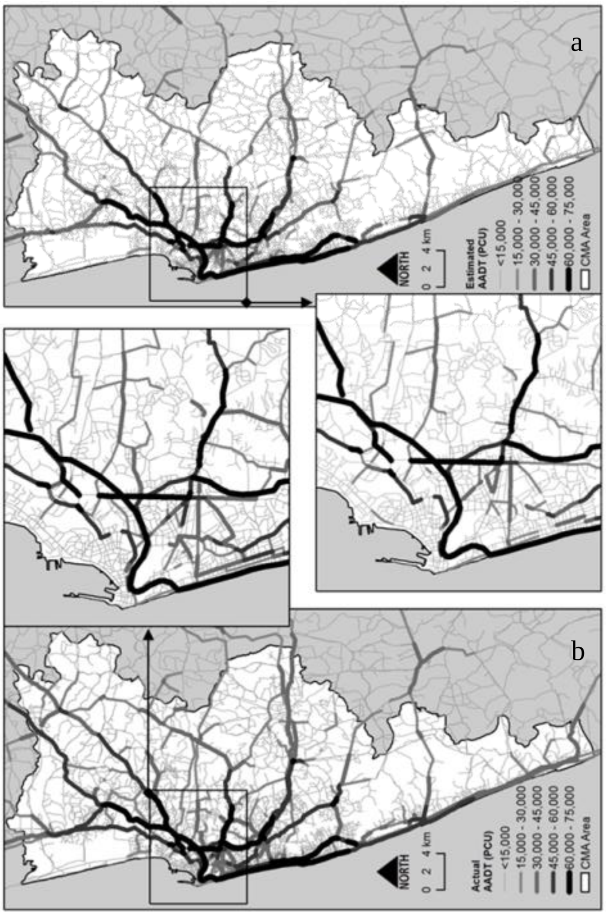

Fig.2 (a) Actual AADT and (b) estimated AADT based on NCA (Note: Case study area is Colombo, Sri Lanka and Overall Predictability is 89%)

Identification of strategic projects for investments is a crucial decision. When engineers and planners make decisions on selecting location for multimodal stops or other network improvements, it is very important to identify the hierarchy of transport networks in corridors and stations. Our studies in India and Sri Lanka have revealed that NCA can be effectively used for this purpose (refer **Fig.3 & Fig.4**).

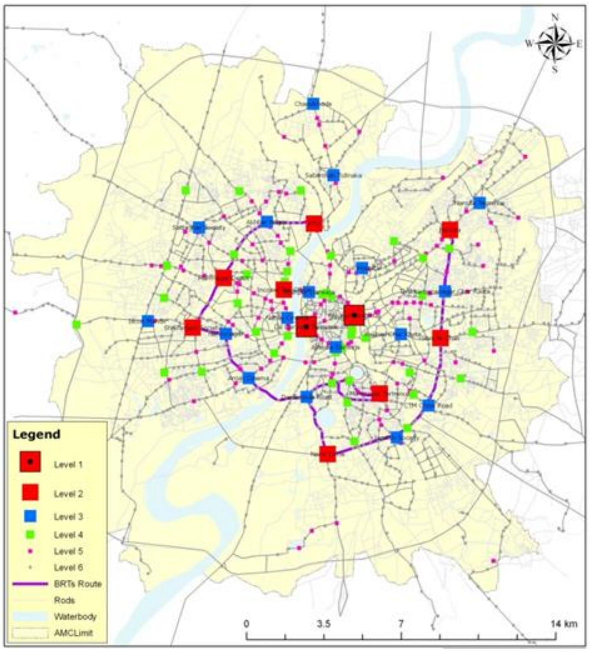

Fig.3 NCA as a tool to identify the hierarchy of transport networks, Case study transits network - Ahmedabad, India

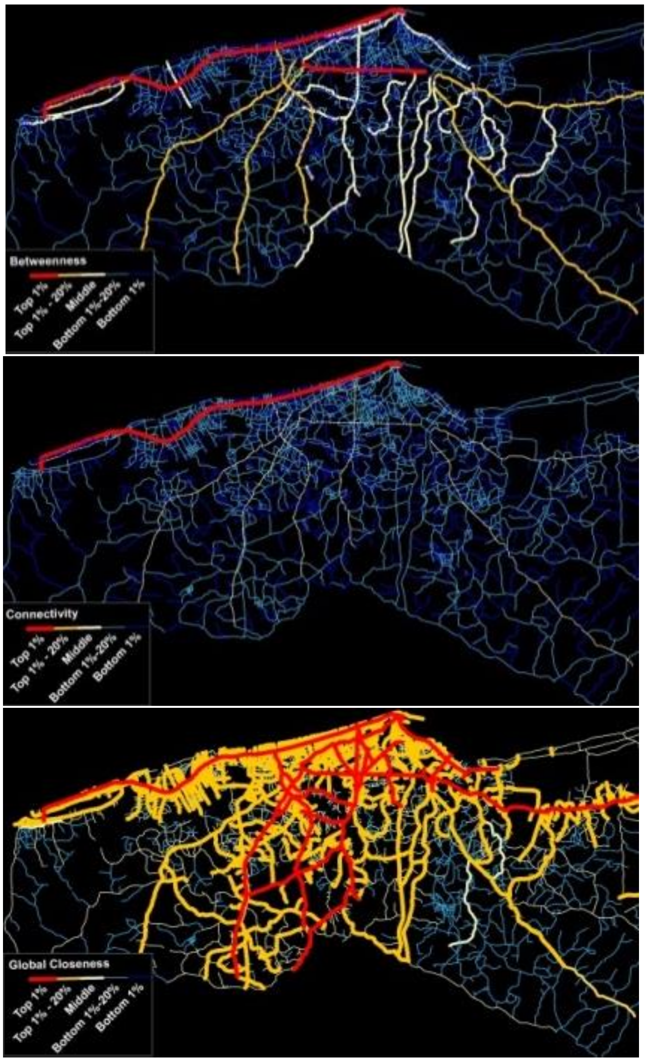

Fig.4 NCA as a tool to Examination of Structural Coherence, Case study road network – Colombo, Sri Lanka (refer **Table 4)**

Table 4 Distribution of road according to the centrality, Case study road network – Colombo, Sri Lanka

Levels	BCC	% of street length	GCC	% of street length	CC	% of street length
Top 1%	>0.17	1.1	>2.20	8.4	>163	1.4
Top 20%	0.17-0.14	4.9	2.20-1.78	40.5	163-131	1.4
Bottom 20%	0.02-0.01	85.9	1.43-0.63	25.7	31-3	71.1
Bottom 1%	<0.01	32.1	<0.63	1.0	<3	29.9

4. CONCLUSIONS AND RECOMMENDATIONS

We have developed an innovative method for traffic simulations especially applicable in developing countries, which will ultimately facilitate investment decisions. The proposed method has been developed based on centrality concept and most notably does not require either detailed database on land use and O-D trip data or advanced technical know-how as it requied for multi-step demand models. The NCA is developed by incorporating mobility characteristics and route choice characteristics, which are described in the notion of origin-destination in the multi-step demand modeling framework into the notion of 'Space Syntax', Further, we have demonstrated capabilities of NCA as a strategic planning and investment tool based on case studies from India and Sri Lanka.

Accordingly, this study suggests that NCA which is currently not in practice has a potential to be utilizes as a strategic planning and investment tool in urban areas in developing countries, especially because NCA can efficiently work under data, cost and technical know-how constrained situations. An essential extension of this study would be validation and improvement of it's` simulation capabilities with more case studies in developing countries in the future.

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(Received July 27, 2016)