USES OF HIGH-RESOLUTION IMAGERY FOR URBAN TRANSPORTATION APPLICATIONS: QUANTITATIVE INDICES EXTRACTION APPROACHES

K. Lee [a], K.- H. Chi [b]

[a] Dept. of Information Systems, Hansung University, Seoul, 136-792, KOREA - kilee@hansung.ac.kr
[b] KIGAM(Korea Institute of Geoscience and Mineral Resources), Daejeon-city, 305-350, KOREA - khchi@rock25t.kigam.re.kr

KEY WORDS: Extraction, High resolution, GIS, Indicators, Urban

ABSTRACT:

Recently, new approaches with commercial high-resolution satellite imagery in the engineering application domains have been attempted. Among them, uses of remotely sensed imagery linked with GIS-T (Geographic Information Systems for Transportation) or transportation geography are regarded as one of prospecting issues. As the matter of facts, most transportation applications are needed real-time or near real-time processing for data acquisition, analysis, or broadcasting; comparatively, uses of remotely sensed imagery in this field are somewhat oriented to periodic change detection and analysis, prediction and forecasting. Even in this approach, high-resolution imagery is more advantageous than coarse and medium resolution imagery. Normally, two kinds of approaches are prevailed such as image recognition/interpretation and automatic or semi-automatic feature extraction. With this base considerations and engineering viewpoints, practical uses of remote sensed imagery in urban transportation environment analyses were carried out with newly implemented extension programs running under desktop GIS environment in this study: Connectivity index and Circuity index, which mean degree of connectivity and degree of circuit in a network, respectively. As for connectivity index, three types of algorithms such as alpha, gamma, and shimbel index were implemented, and extraction program of circuity and accessibility matrix were implemented with OD (Origin-Destination) matrix computation used in travel demand analysis in transportation geography. In both cases, high-resolution imagery is used in determination of user-defined arbitrary analysis zone or AOI (Area Of Interest), corresponding to TAZ (Traffic Analysis Zone) in GIS-T and real-time GIS database updating such as road boundary, centerline and other target features on the scene. Therefore, after user selects AOI and updates database, these indices can be easily computed using implemented program in this study. By this approach, new quantitative information to characterize an urban transportation environment in a certain region can be easily obtained and utilized as meaningful indicators related to transportation planning process or urban planning, comparing with those results produced without high-resolution imageries.

1. INTRODUCTION

As various types of engineering applications dealing with geo-spatial imagery such as commercial uses of high-resolution satellite imagery are possible, analytical GIS-based technology on geo-spatial imagery has been studied. Utility of geo-spatial imagery in the applications for urban transportation analysis, which often refers to GIS-T (GIS for Transportation) and GIS network analysis functionalities, is regarded as one of these approaches (Khuen, 1997; Lang, 1999; Donnay *et al*., 2001; Miller and Shaw, 2001). Most analytical functions in GIS-based network analysis are based on problem-solving methodology in the transportation geography (Han, 1996; Chou, 1999).

Lo and Yeung(2002) summarized that there are two main groups in measures for network analysis in the geography: one is to extract overall characteristic based on a topological graph or topological graphs, and the other is to compute the shortest or optimal path finding and allocation segments. Currently, most commercial geo-processing software systems provide network analysis modules. However, feasible functions to extract basic quantitative indices for transportation network structure in a certain region are rare in those systems. Recently, some studies to implement fundamental functions using geo-spatial imagery based on GIS have been carried out and tentatively tested (Lee, 2002; Lee *et al*., 2003).

Main focuses in this study are on implementation to extract basic connectivity indices related to transportation network: alpha index and gamma index, which are known as fundamental information to delineate a given network structure, and shimbel index, circuity/connectivity/accessibility in the matrix form. Especially, these GIS-based spatial metrics are known to provide useful quantitative information for urban transportation analysis, and each index provides individual significance to interpret a given network structure. Geo-spatial imagery including high-resolution imagery or digitally processed airborne photograph can also be effectively used as a base image in these applications.

In this study, an extension program for automatic computation of those indices is newly implemented in Avenue™, as AVX extension programs running on ESRI-ArcView® GIS. These extension programs in AVX-complied are different from other ones such as (Ormsby and Alvi, 1999) and Lee and Wong (2001). On application of this program, it is designed that spatial database such as road centerline or network structure with nodes and administrative boundary is needed as the user-sided minimum requirements. Some case studies regarding practical application of these programs are presented mainly with KOMPSAT EOC.

2. TYPES OF QUANTITATIVE INDICES FOR TRANSPORTATION ANALYSIS

2.1 Connectivity Indices and Shimbel index

To measure the spatial network structure, topological measures of network structure based on gross characteristics and the cyclomatic number can be used (Lo and Yeung, 2002), which is represented by numbers of vertexes or nodes and those of edges or links in the graph.

In general, connectivity terms the connected quantity between nodes in a given network, to extract overall structure of transportation network. It is regarded as one of important information to assess transportation network (Han, 1996). Several types of connectivity index, in which each index has its own applicable meaning, are developed in the domain of transportation geography: alpha index, gamma index, and shimmel index.

Especially, it is known that alpha index and gamma index measure the most fundamental properties of a network. As for a basic application of these indices for connectivity measurement, periodic change of road network structure in a given boundary of ROI (Region of Interests) or traffic analysis zone shown in Fig. 1 can be significantly quantized and compared.

As shown in Figure 1, extraction of connectivity index needs some requirements such as road centre-line representing road network structure composed of transportation nodes. A transportation node is point feature, composing transportation network or topological structure. In some cases, it can be processed as target-based node point, where target means a point-typed feature for a given application purpose.

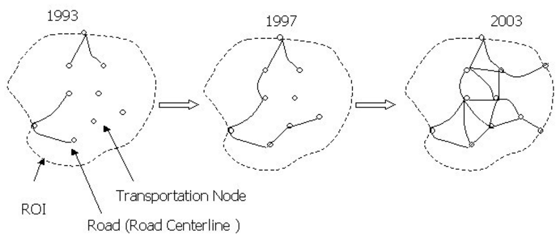


Figure 1. Use case of degree of connectivity for transportation analysis

As one of important connectivity indices, alpha(α) index is defined as the ratio of actual number of circuits to the number of maximum circuits in the network (Chou, 1999), where a circuit is a loop in the network and is composed of nodes and links (equation 1).

This quantity is useful to evaluate network structure in terms of the number of the ways that proceed from one node to another, and can be used in comparing and differentiating the connectivity levels of different networks. The following equation in a planar graph is used to obtain Alpha index in a network ranging from 0 and 1.

$$\alpha = \frac{e - v + 1}{2v - 5} \quad (1)$$

where α = alpha index
e, v = number of link (or edge) and node (or vertex) in a circuit

Gamma(γ) index is defined as the ratio of the actual number of edges to the maximum possible number of edges in the network. In a planar graph, gamma index can be computed as quantity of actual number of links divided by the maximum number of links (equation 2).

It is known that this is useful for comparing two or more network structures in transportation analysis. This index ranges 0 to 1.

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

where γ = gamma index

A well-developed transportation network has higher values on both alpha and gamma indices which correspond to higher levels of complexity and connectivity. But in the non-planar graphs of 3-dimensional case, different forms should be applied for these indices.

Unlike these two fundamental indices, shimbel index, *D(G)*, is summation of all the shortest path distances($d_{ij:}$) among all points (vertex and node) in a defined zone or a circuit (equation 3). Especially, this is useful in evaluating concentrated levels of transportation networks in urban transportation analysis.

$$D(G) = \sum_{i=1}^{n} \sum_{j=1}^{n} d_{ij} \quad (3)$$

where $D(G)$ = shimmel index
$d_{ij:}$ = shortest path between *i* node to *j* node

In this study, it is designed that these indices can be computed in a same user interface. For it, two types of spatial layer, which are most fundamental information in GIS-based urban applications, are needed: administrative boundary and road centerline. These layers can be directly obtained from digital map datasets, or these can generate using generic GIS tools or CAD tools. In any cases, it is possible to define node and polyline elements.

Figure 2 represents implementation result of connectivity analysis's user interface, composed of Select layer, Select boundary type, and Extract, with IKONOS imagery. Followed by determining target layer in < Step 1 >, function of 'Select boundary types' of <Step 2> is to choose analysis zone to automatically extract nodes in <Step 3>. It shows selected name, coordinate, area. If selection of "Extract Road node" button in <Step 3>, edge(e) and vertex(v) are abstracted automatically. Finally, alpha, gamma, Shimbel index are calculated by "Calculate index" button control.

Computed results are shown in 'Index info' in this dialog. In this process, geo-spatial imagery can be effectively used to find out spatial features related to analysis zone selection in an arbitrary polygon. Digital layers and rectified geo-spatial imagery of a certain city nearby Seoul are used in Figures 3 and 4.

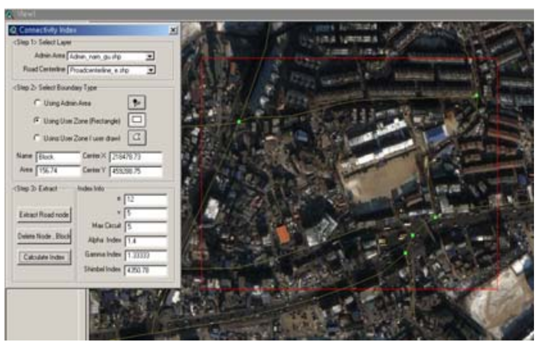


Figure 2. User interface of extraction extension program of Connectivity index with IKONOS imagery

If users estimate degree of transportation networks in a certain interested region, they need base data such as high-resolution geo-spatial imagery containing spatial features on it.

In this case, although two types of layers are also necessary, application scheme is a quite different from the former case dealing with district areas.

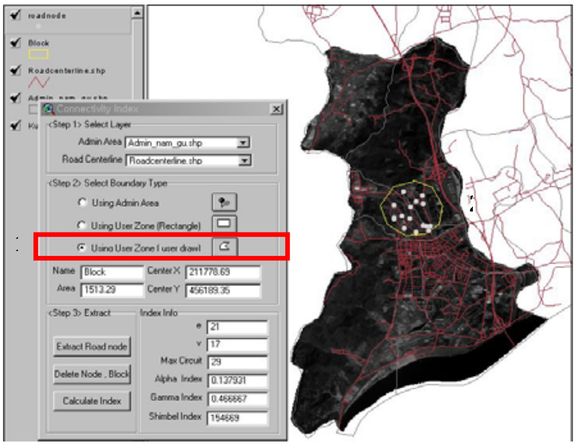


Figure 3. User input interface for computation of connectivity indices. 'User draw' button in step 2 processes user-defined arbitrary boundary (A). B shows an arbitrary region, which can be determined by users, where nodes are automatically extracted in it.

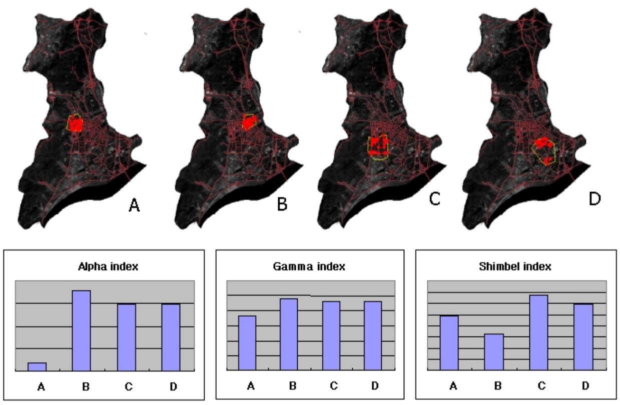


Figure 4. Actual application case using connectivity measures following by figure 3.

In figure 4, the four sites of A, B, C, and D are arbitrarily chosen as test sites in the map display window. As known from results of indices values, the degree of connectivity of networks, alpha and gamma indices, does not show consistent pattern. Moreover, the degree of transportation concentration, as shimbel index, is somewhat distinguished in the B site.

In this case, different patterns in alpha and gamma indices give practical meaning that both indices can be considered for the network structure analysis. The reason on low value in shimbel index in B site is that this are considered actual distances between nodes in a block.

2.2 Circuity and Level of Accessibility in the Matrix Form

Similar to previous road-specific measures, transportation domain-specific demands with respect to practical applications and analysis scheme using spatial thematic information are increasing. Accordingly, GIS-based application program is implemented to perform spatial analysis in transportation geography with base road layer data. Among several approaches, quantitative estimation of circuity and accessibility, which can be extracted from nodes composed of the graph-typed network structure, in a arbitrary analysis zone or administrative boundary zone is possible.

Circuity is a concept to represent the difference extent between actual nodes and fully connected nodes in the analysis zone.

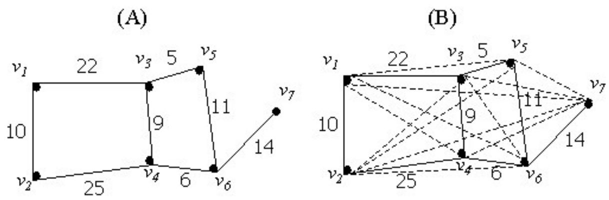


Figure 5. (A) Example of Road network with distance, (B) Fully connected road graph network.

$$C_i = \frac{1}{n}\sum_{j=1}^{n}[d(i,j) - e(i,j)]^2 \qquad (4)$$

where C_i = circuity value at the ith node in a geven graph
n = number of nodes in the graph or zone
$d(i,j)$, $e(i,j)$ = desired distance or weight value and actual one between ith and jth node

While, accessibility matrix [A] in equation (5) can be used to find out extent of accessibility or connectivity between all nodes contained in the analysis zone, judging from inter-connecting status of the whole nodes. Input data of this program is not transportation database information based on transportation data model, but layer data, directly obtaining from digital map sets. It is thought that computation of circuity and accessibility can be used as kinds of spatial analysis functions for GIS applications in the transportation field.

$$[C^2] = [C^1][C^1]$$
$$[C^3] = [C^1][C^2] \qquad (5)$$
$$[A] = [C^1] + [C^2] + [C^3]$$

where C^1 can be obtained as below in case of figure 5,

$$C^1 = \begin{bmatrix} 0 & 1 & 1 & 0 & 0 & 0 & 0 \\ 1 & 0 & 0 & 1 & 0 & 0 & 0 \\ 1 & 0 & 0 & 1 & 1 & 0 & 0 \\ 0 & 1 & 1 & 0 & 0 & 1 & 0 \\ 0 & 0 & 1 & 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 & 1 & 0 & 1 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 \end{bmatrix}$$

Computation of circuity is firstly definition of desired road graph network in the form of fully connected one, *d(i,j)*, and then compare it with actual road graph network, *e(i,j)*, in a certain analysis zone. As the result in the case of figure 5, v_1 and v_7 is nodes showing large level of circuity. Level of accessibility is also related to the circuity computation process. Inter- connected nodes in the same road graph are assigned to unit value, and this result can be represented to square matrix form, C^1. This result can be directly utilized to obtain accessibility level in the form of matrix. It represents easiness of access among nodes in a given zone.

Figure 6. Input data for computation of Circuity and Accessibility: road graph layer and base imagery

Figure 6 shows input data for circuity and accessibility matrix computation. While, figure 7 is user interface of application program and processing steps: <Step 1> ~ <Step 4>. In this environment, first three steps are same to connectivity measure on road network. Through <Step 4-1> and <Step 4-2> are for calculation of circuity value at a node, each point, in the analysis zone and calculation of circuity, connectivity, and accessibility of the whole nodes in the analysis zone and their representation in the matrix form, respectively.

The result of <Step 4-2 > is represented at figure 8, in the normalized matrix form with maximum value of 1. Figure 9 shows network connectivity and accessibility matrix with figure 7.

3. CONCLUSION

It is known that high-resolution imagery is more advantageous than coarse and medium resolution imagery. In this study, GIS-based extraction application program for road characteristics is implemented and tested in the viewpoint of practical uses of those imageries.

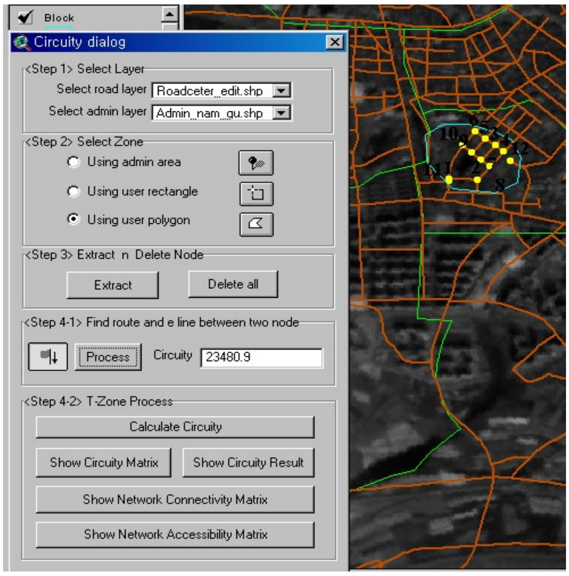
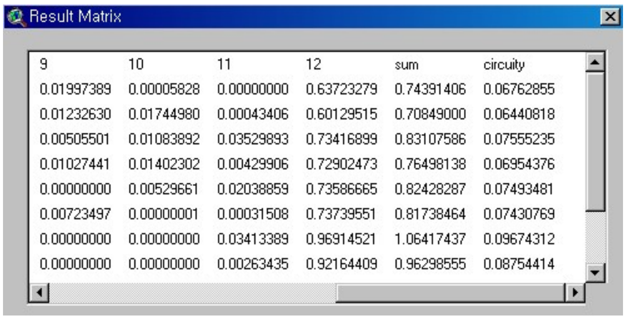
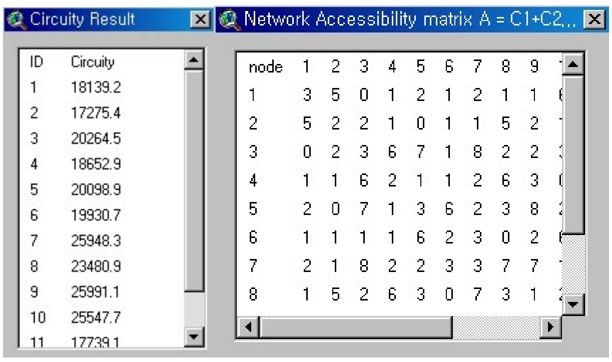


Figure 7. User interface of application program and processing steps: <Step 1> Input layers of road centerline and administrative boundary, <Step 2> Selection of analysis zone, <Step 3> Automatic extraction of nodes within the analysis zone, <Step 4-1> Calculation of circuity value at a node in the analysis zone, <Step 4-2> Calculation of circuity, connectivity, and accessibility of the whole nodes in the analysis zone and their representation in the matrix form


Result Matrix

9	10	11	12	sum	circuity
0.01997389	0.00005828	0.00000000	0.63723279	0.74391406	0.06762855
0.01232630	0.01744980	0.00043406	0.60129515	0.70849000	0.06440818
0.00505501	0.01083892	0.03529893	0.73416899	0.83107586	0.07555235
0.01027441	0.01402302	0.00429906	0.72902473	0.76498138	0.06954376
0.00000000	0.00529661	0.02038859	0.73586665	0.82428287	0.07493481
0.00723497	0.00000001	0.00031508	0.73739551	0.81738464	0.07430769
0.00000000	0.00000000	0.03413389	0.96914521	1.06417437	0.09674312
0.00000000	0.00000000	0.00263435	0.92164409	0.96298555	0.08754414

Figure 8. Processing results of <Step 4-2> in Fig. 7: Normalized circuity matrix


Circuity Result

ID	Circuity
1	18139.2
2	17275.4
3	20264.5
4	18652.9
5	20098.9
6	19930.7
7	25948.3
8	23480.9
9	25991.1
10	25547.7
11	17739.1

Network Accessibility matrix A = C1+C2...

node	1	2	3	4	5	6	7	8	9
1	3	5	0	1	2	1	2	1	1
2	5	2	2	1	0	1	1	5	2
3	0	2	3	6	7	1	8	2	2
4	1	1	6	2	1	1	2	6	3
5	2	0	7	1	3	6	2	3	8
6	1	1	1	1	6	2	3	0	2
7	2	1	8	2	2	3	3	7	7
8	1	5	2	6	3	0	7	3	1

Figure 9. Processing results of <Step 4-2> in Fig. 7: (Left) Network connectivity matrix for $[C^1]$, (Right) Network accessibility matrix for $[A]$ with respect to the whole nodes in the analysis zone

As for connectivity index, three types of algorithms such as alpha, gamma, and shimbel index were implemented, and level of circuity, as well as accessibility, was implemented in order to produce the results of OD (Origin-Destination)-styled matrix computation used in travel demand analysis in transportation geography. In both cases, high-resolution imagery is used in determination of user-defined arbitrary analysis zone or AOI (Area Of Interest), corresponding to TAZ (Traffic Analysis Zone) in GIS-T and real-time GIS database updating such as road boundary, centerline and other target features on the scene.

By this approach, new quantitative information to characterize an urban transportation environment in a certain region can be easily obtained and utilized as meaningful indicators related to transportation planning process or urban planning, comparing with those results produced without high-resolution imageries

4. REFERENCES

Chou, Y.H., 1997. *Exploring Spatial Analysis in Geographic Information Systems*. Onwards Press. 452pp.

Donnay, J.-P., M. J. Barnsley, and P. A. Longley, 2001. *Remote Sensing and Urban Analysis*, GISDATA 9 Series, Taylor and Franscis.

Easa, S. and Y. Chan (ed). 2000. *Urban Planning and Development Applications of GIS*. ASCE. 283pp.

Han, J. S., 1996. *Transportation Geography*. Bupmun-sa, 438 pp (in Korean).

Khuen, B., 1997. Commercial Application for High Resolution Geo-spatial Imagery, *PE&RS*, 63: 933-941

Lee, J. and D. W. S. Wong. 2001. *Statistical Analysis with ArcView GIS*. John Wiley and Sons.

Lee, K. 2002. Extraction of Some Transportation Reference Planning Indices using High-Resolution Satellite Imagery, *Korean Journal of Remote Sensing*, 18(5), pp. 263-271.

Lee, K. and S. K. Oh. 2003. Application of Quantitative Indices for Urban Environment Analysis in the Consideration of Remote Sensed Imagery: Accessibility and Connectivity. *ACRS-ISRS 2003 Proceedings*.

Lo, C. P. and A. K. W. Yeung, 2002. *Concepts and Techniques of Geographic Information Systems*, Prentice Hall Series in Geographic Information Sciences, 492pp.

Ma, M. L. and L. S. C. Pun-Cheng. 2000. The Study of Accessibility Indices in Transportation Planning by using Geographic Information Systems. *URISA Conference*.

Miller, H. J. and S. L. Shaw. 2001. *Geographic Information Systems for Transportation (GIS-T): Principles and Application*. Oxford University Press.

Ormsby, T. and J. Alvi. 1999. *Extending ArcView GIS: with Network Analyst, Spatial Analyst and 3D Analyst*. ESRI Press. 527pp.