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Indices Characterizing Road Network on Geo-Spatial Imagery as Transportation Network Analysis

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Abstract : In GIS-based network analysis, topological measure of network structure can be considered as one of important factors in the urban transportation analysis. Related to this measure, it is known that the connectivity indices such as alpha index and gamma index, which mean degree of network connectivity and complexity on a graph or a circuit, provide fundamental information. On the other hand, shimbel index is one of GIS-based spatial metrics to characterize degree of network concentration. However, the approach using these quantitative indices has not been widely used in practical level yet. In this study, an application program, in complied as extension, running on ArcView-GIS is implemented and demonstrated case examples using basic layers such as road centerline and administrative boundary. In this approach, geo-spatial imagery can be effectively used to actual applications to determine the analysis zone, which is composed of networks to extract these indices. As the results of the implementation and the case examples, it is notified that alpha and gamma indices as well as shimbel index can be used as referential data or auxiliary information for urban planning and transportation planning.

Key Words : Alpha Index, ArcView-GIS, Gamma Index, Road Centerline, Shimbel Index.

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; US DOT/NASA, 2002). Most analytical functions in GIS-based network analysis are based on problem-solving methodology in the transportation geography (Chou, 1999; Han, 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

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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, 2003; Lee *et al.*, 2003).

Main focus in this study is 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. 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. 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 and discussed with KOMPSAT EOC.

2. Quantitative 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, 1999). 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.

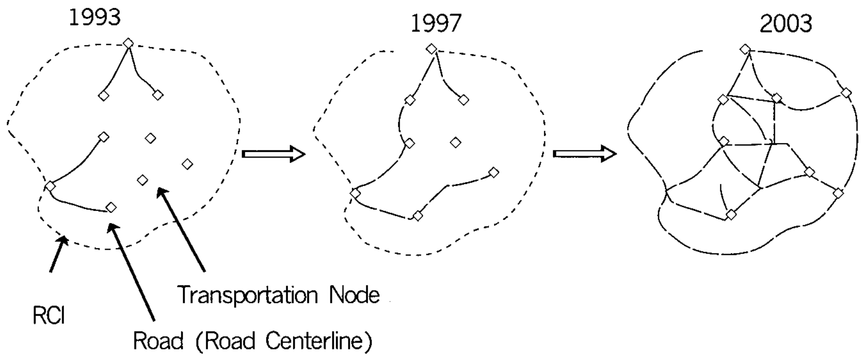

Fig. 1. Progress on degree of connectivity for transportation analysis.

As shown in Fig. 1, extraction of connectivity index needs some requirements such as road centerline 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.

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. 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.

$$\alpha = \frac{e - v + 1}{2v - 5} \tag{1}$$

where e and v are the number of link (or edge) and node (or vertex) in a circuit, respectively.

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

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

where e and v are the number of link (or edge) and node (or vertex) in a circuit, respectively.

In general, 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. Especially, this is useful in evaluating concentrated levels of transportation networks in urban transportation analysis.

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

where d_{ij} means distance to 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.

Figs. 2, 3, and 4 represent three processing steps: Select layer, Select boundary type, and Extract. In those, function of 'Select boundary types' of step 2 is to choose analysis zone to automatically extract nodes in step 3. After user finishes requesting node-extraction in <Step 3>, 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 Guri city are used in Figs 2, 3, and 4.

3. Case Examples

Extension program for extraction of connectivity indices and shimbel index is implemented in this study. It can be practically used in several approaches related to

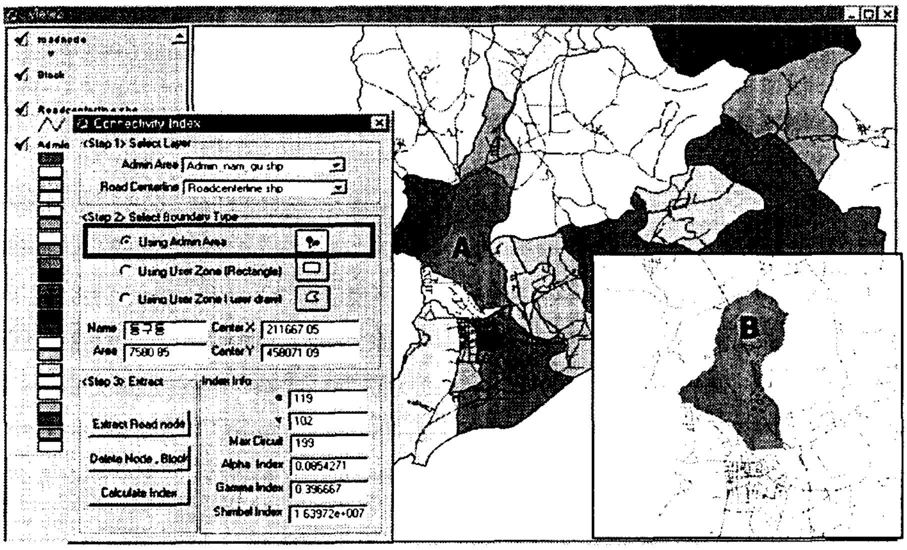

Fig. 2. User input interface for computation of connectivity indices. 'Admin area' button in step 2, followed by step 1 to select data layers, is to perform automatic selection of boundary of administrative district. A and B area represent the same region.

quantitative urban transportation analysis.

Alpha index and gamma index can be used to quantitatively compare different networks differentiating their levels of connectivity, and shimbel index provides

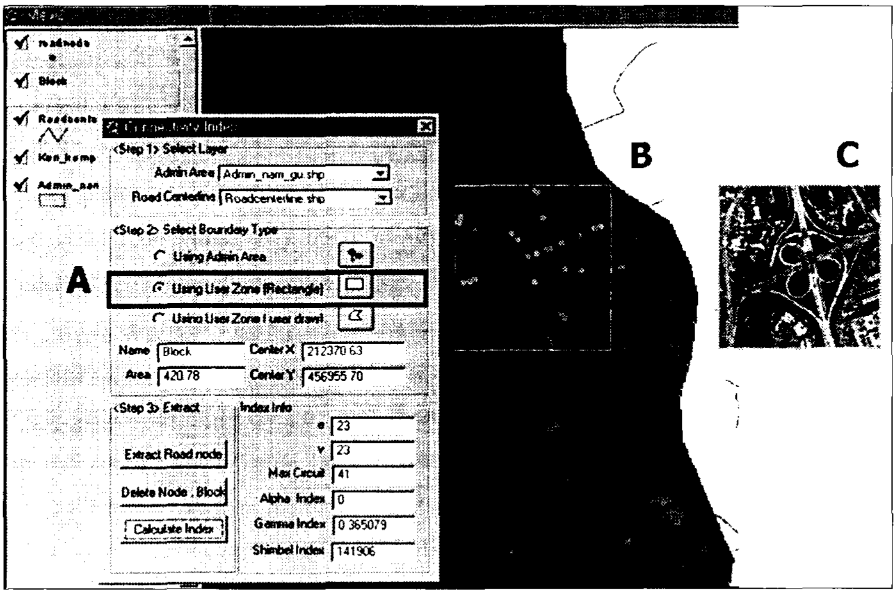

Fig. 3. User input interface for computation of connectivity indices. Rectangle button in step 2 processes user-defined box area (A). B and C show KOMPSAT EOC and IKONOS as a reference image, respectively, in the selected rectangle region.

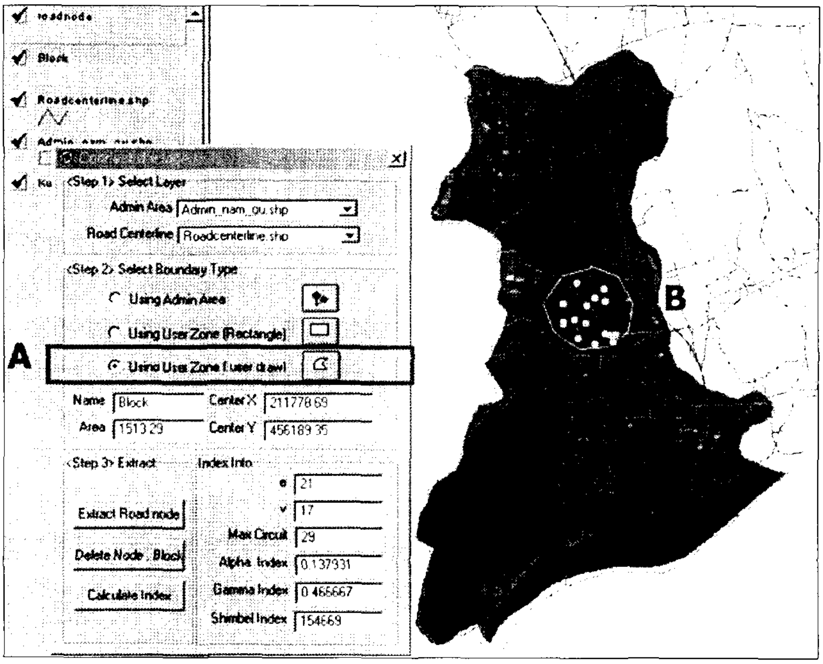

Fig. 4. User input interface for computation of connectivity indices. 'User draw' button in step 2 processes user-defined arbitrary boundary (A). B shows an arbitrary region, which can be determined by users, where nodes are automatically extracted in it.

useful information to evaluate concentration levels of the concerned networks.

In the application, network would be network structures at different regions, and network at different time in the same region. In this study, the former cases are selected as test cases using basic layers of road center-line and administrative boundary and KOMPSAT 1 EOC imagery for the entire region of Guri city, nearby Seoul shown in Figs. 5 and 6.

Fig. 5 shows the first case result from administrative boundaries in the tested area. This corresponds to the process of Fig. 2. However, geo-spatial imagery in this case is not considered because analysis zones are already built in databases. From these results at the five administrative district areas, it is shown that alpha and gamma indices to measure the degree of connectivity of networks show correlated pattern, although detailed interpretation for these indices values is not presented in this study. In some extent, it needs analytical explanation in transportation domain.

Judging from relatively values of shimbel index to evaluate degree of transportation concentration, road network structure of transportation in this area is well organized.

This kind of approach is useful to understand overall quantitative analysis of transportation networks among districts in a local government. But it is dependent upon spatial accuracy of layers and types of transportation nodes. Therefore, this result can be provided as reference data or auxiliary information for further analysis related to urban planning and transportation planning task.

Fig. 6 shows another case using this extension program. This example corresponds to the process of Fig. 4. If users estimate degree of transportation networks in a certain interested region, they need base

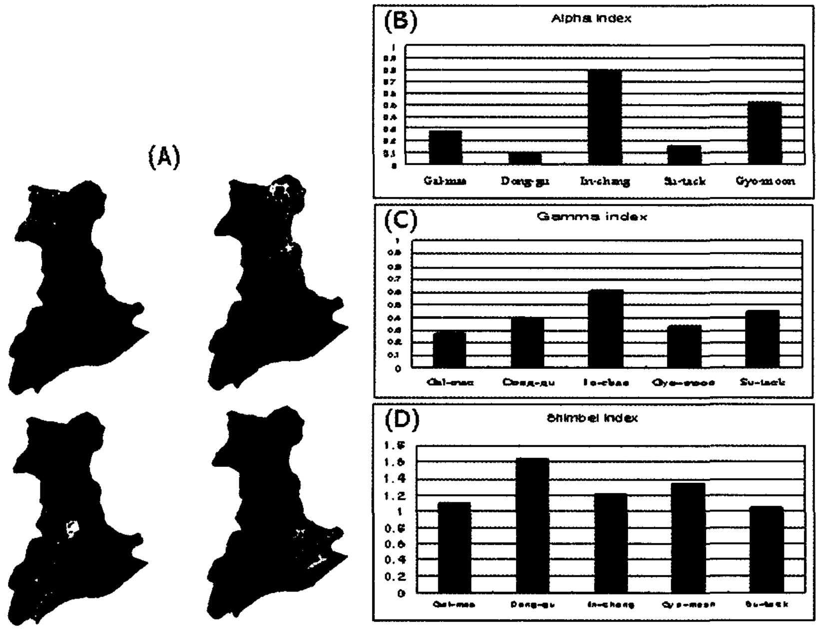

Fig. 5. Applied case of connectivity index in Guri-city: Colored points in (A) mean nodes within one of administrative districts. (B), (C) and (D) represent connectivity indices with respect to some district areas.

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

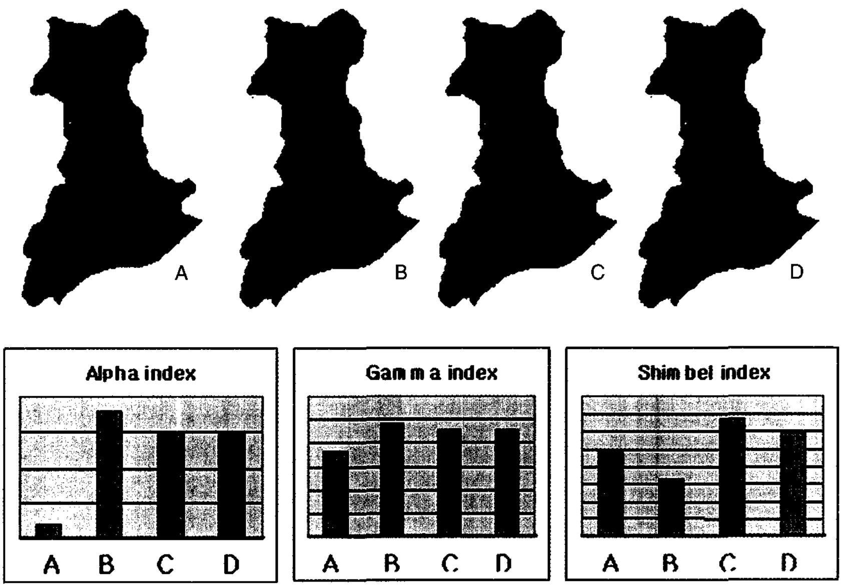

Fig. 6. Applied case of connectivity index in Guri-city: Red-color points in A mean nodes within arbitrarily selected analysis zones.

the former case dealing with district areas.

At first, 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.

On the other hand, alpha and gamma indices take into account circuit or graph in the networks, regardless of block size. In the case of B site, though the degree of connectivity is high, value of shimbel index is not high. It is suggested that the same block size as rectangle boundary in Fig. 3 is needed for using of shimbel index and its interpretation.

4. Conclusions

Various types of geo-spatial imagery have been utilized in many application fields. In this study, GIS-based implementation for extraction of connectivity indices based on a graph or a circuit is performed. Connectivity indices, which provide degree of network connectivity and complexity and degree of network concentration, are known as useful information for urban transportation analysis, especially quantitative analysis of road network, but these concepts are not widely used yet.

This developed extension program could be easily applied in some practical problems, because it is running on ArcView®-GIS, one of the most used desktop software systems. This program needs basic requirements for urban transportation analysis: digital map sets composed of layers such as road centerline and administrative boundary and geo-spatial imagery in the rectified level. Especially, it is designed to effectively use geo-spatial imagery in the determination of analysis zones such that users can select their interested regions.

As results of case examples show, it is concluded that alpha and gamma indices as well as shimbel index can be used as auxiliary information for preliminary quantitative studies and referential data for urban planning and transportation planning task in local governments.

Acknowledgements

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