Integrated Approach of Spatial Metrics by Graph-based Road Network on Remotely Sensed Imagery for Urban Transportation Planning

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ABSTRACT – In these days, remotely sensed imagery has been widely used for GIS-T (Geographic Information Systems for Transportation). As for this approach, topological measure and spatial metrics of transportation network structure such as road layer can be considered as one of important factors in urban transportation analysis. Related to this measure, it is known that the connectivity such as alpha index and gamma index which means degree of network connectivity and complexity on a graph or a circuit, provide useful information for urban transportation planning. As well, 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 the practical level dealing with actual data sets yet. While, as other spatial metrics, circuity terms a concept to represent the difference extent between actual nodes and fully connected nodes in the target analysis zone, and accessibility is used to represent accessibility level in the matrix form by connectivity level between node to node in a zone. In this study, several spatial metrics functions, such as connectivity, accessibility, and circuity, mentioned above were first implemented to extract transportation indices from a graph-based network. In conclusions, 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 transportation planning.

Keywords: Extraction, High resolution, GIS, Indicators, Urban

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; 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 (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 graph-based analysis functions using geo-spatial imagery have been carried out (Lee, 2002; Lee *et al*., 2003).

Main focuses in this study are integrated uses using several types of spatial metrics functions such as connectivity related to transportation network: alpha index and gamma index and shimbel index, circuity, and accessibility. Especially, these GIS-based spatial metrics are known to provide useful quantitative information for urban transportation environmental 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 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 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 SPATIAL METRICS FOR TRANSPORTATION ANALYSIS

2.1 Connectivity Indices and Shimbel index

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. 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 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. 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.

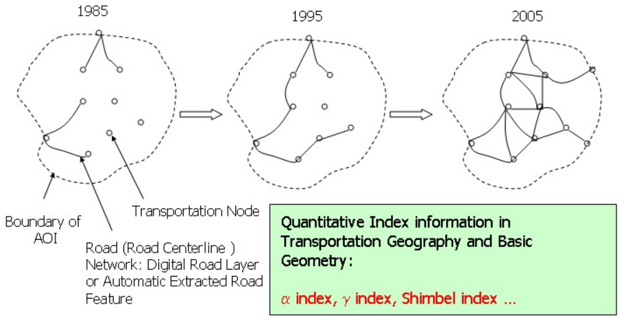

Figure 1. Basic concepts of connectivity, as spatial metrics.

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. 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.

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. Beside these two fundamental indices, shimbel index to represent summation of all the shortest path distances 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. 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 (Fig. 2).

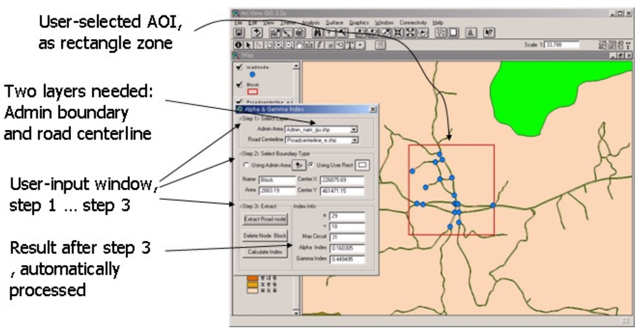

Figure 2. User interface of connectivity analysis on the GIS layers, and the processing steps.

Figs 3 and 4 represent implementation result of connectivity function and its user interface, composed of Select layer, Select boundary type, and Extract, with satellite 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.

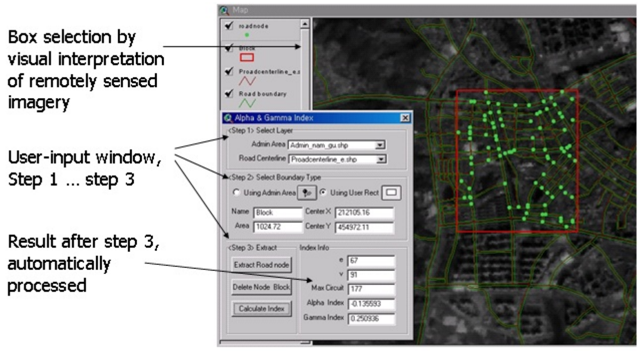

Figure 3. Case of connectivity analysis with satellite imagery in a rectangle region.

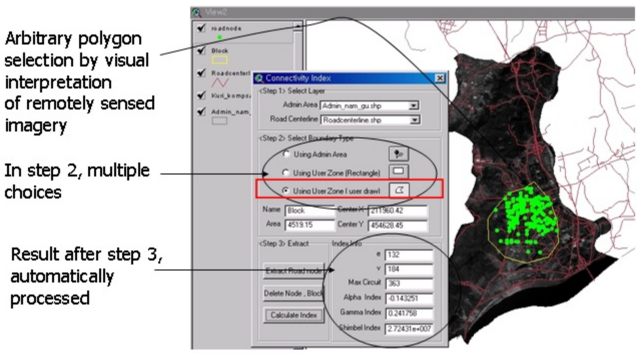

Figure 4. Case of connectivity analysis with satellite imagery in an arbitrary region.

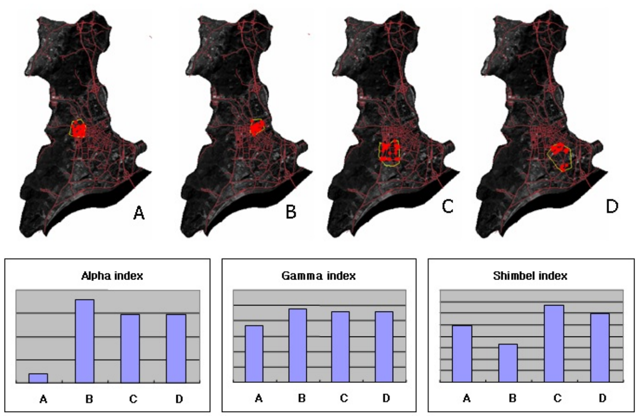

Figure 5. Case of connectivity analysis on base image.

As well, figs 3 and 4 represent some actual cases using this application program in a rectangle and arbitrary region as target zone to analyze, respectively. The result of this processing can be obtained at the several target zones such as that of Fig 5, though it is a simple case. In figure 5, the four regions of A, B, C, and D are arbitrarily chosen as test regions 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.

2.2 Circuity and Level of Accessibility

Circuity is a concept to represent the difference extent between actual nodes and fully connected nodes in the analysis zone (Fig. 6). Input data of this program is not transportation database information based on transportation data model, but layer data obtained from digital map sets directly.

Computation of circuity firstly needs definition of desired road graph network in the form of fully connected one. Then it is compared it with actual road graph network in a certain analysis zone. 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.

While, figure 8 is user interface of application program and processing steps: <Step 1> ~ <Step 4>. In this environment, first three steps are same as 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.

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. 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.

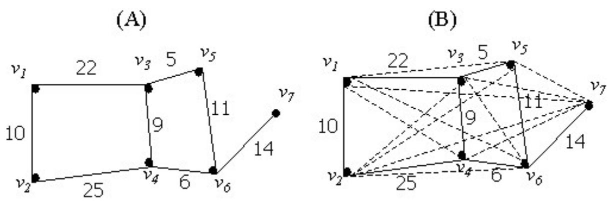

Figure 6. (A) Example of Road network with distance, (B) Fully connected road graph network.

Figure 9 show simple application workflow using spatial metrics functionality.

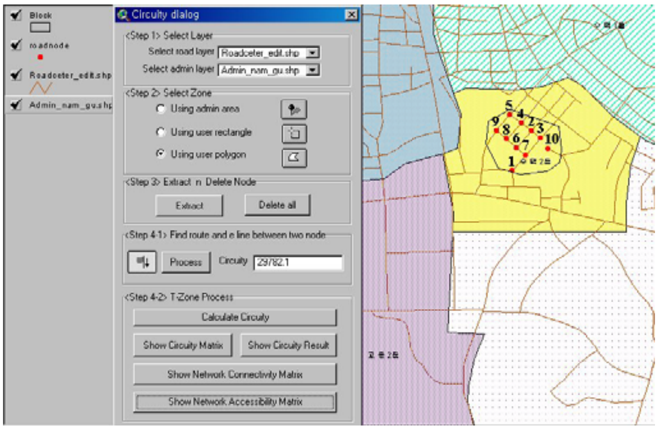

Figure 7.User interface Circuity/accessibility analysis with basic GIS layers.

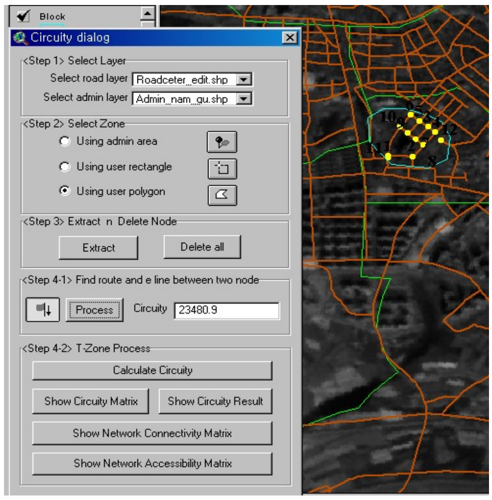

Figure 8. Circuity/accessibility analysis with space-borne imagery.

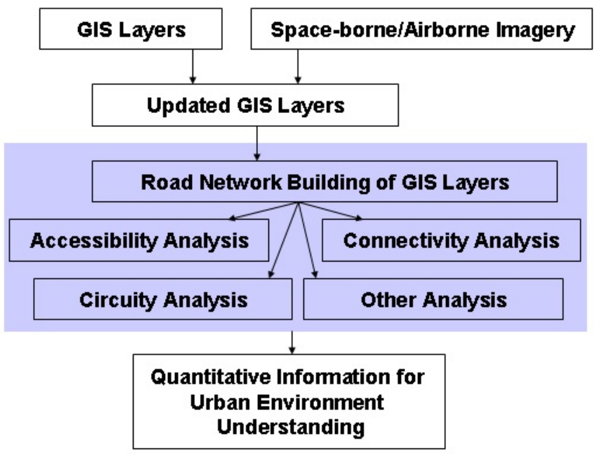

Figure 9. Workflow for the integrated processing.

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. 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 to those results produced without high-resolution imageries.

4. REFERENCES

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