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Extraction of Some Transportation Reference Planning Indices using High-Resolution Remotely Sensed Imagery

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Abstract : Recently, spatial information technologies using remotely sensed imagery and functionality of GIS (Geographic Information Systems) have been widely utilized to various types of transportation-related applications. In this study, extraction programs of some practical indices, to be effectively used in transportation reference planning problem, were designed and implemented as prototyped extensions in GIS development environment: traffic flow estimation (TFL/TFB), urban rural index (URI), and accessibility index (AI). In TFL/TFB, user can obtain quantitative results on traffic flow estimation at link/block using high-resolution satellite imagery. Whereas, URI extension provides urban-rural characteristics related to road system, being considered one of important factors in transportation planning. Lastly, AI extension helps to obtain accessibility index between nodes of road segments and surrounding district areas touched or intersected with the road network system, and it also provides useful information for transportation planning problems. This approach is regarded as one of RS-T (Remote Sensing in Transportation), and it is expected to expand as new application of remotely sensed imagery.

Key Words : Accessibility Index, High-resolution Imagery, Traffic Flow, Transportation Planning, Urban Rural Index.

1. Introduction

Remotely sensed imageries have been regarded as one of important data sources in spatial information systems, providing mass information to extract for various types of applications such as environmental information analysis, natural resource monitoring, or other many kinds of useful fields. In case of transportation application field among those possible applications based on spatial information, GIS-based approach in that domain is the most active application so that it is called GIS-T (Geographic Information Systems for Transportation) (Lang, 1999; Easa and Chan, 2000).

Applications in GIS-T cover much of the broad scope of transportation. Briefly, in GIS-T, there are many specialized functions related to transportation problems: TAZ (Traffic Analysis Zone) analysis, O-D (Origin-Destination) table analysis, traffic modeling or route planning in network topology, and so on. Transportation analysts and decision makers are using these types of

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GIS-base functionalities in infrastructure planning, design and management, public transit planning and operations, traffic analysis and control, transportation safety analysis, and configuring and managing complex logistics systems (Kim and Kim, 1996; KGS, 1999; Miller and Shaw, 2001).

However, it seems that current functions in GIS-T do not effectively use space-borne remotely sensed data, and high-resolution imagery is used for base image for data representation. Meanwhile, sensor information on a certain traffic site can be obtained as image using real-time and wireless communications, and it is also sensed image information. But only geo-rectified space-borne imagery is used in this study.

Since late 1990s, US DOT (Department Of Transportation) with NASA (National Aeronautics and Space Administration) program has been forced on comprehensive research program for remote sensing in transportation with the following transportation requirements under NCRST (National Consortium on Remote Sensing in Transportation); ① NCRST-F: Traffic surveillance, monitoring, and management, ② NCRST-I: Transportation infrastructure management, ③ NCRST-E: Environmental assessment, and ④ NCRST-H: Hazards and disaster management (U.S DOT/NASA, 1999). Briefly, in transportation problems, NCRST-F supports researches on the subject to develop methods for traffic congestion, mitigation, and flow, as well as facilitating the implementation of these methods. While, NCRST-I does issues on inventory and location of assets, condition management, change detection, and modeling potential hazards to facilities with traditional remotely sensed imageries, hyper-spectral imagery, and LIDAR, in associated with GIS. While, researches on NCRST-E and NCRST-H have interests to disaster problems in relation to road network system. Some general aspects in space-borne sensor imagery in transportation are summarized in Table 1. In addition, possible applications using high-resolution imagery was discussed in Khuen (1997).

While, as for transportation planning as another subject in this study, the objective of transportation planning is to guide development of a land-use/transportation system to achieve beneficial economic, social, and environmental outcomes. This includes tactical decisions such as planning new right-a-ways or public transit routes, and also includes long-term, strategic planning of the entire land-use transportation system (US DOT/NASA, 1999; Lee, 2001; Wiggins *et al.*, 2001).

Therefore, transportation planning is always complicated task, dealing with various types of data and factors. Recently, this task can be performed as one of important applications based on GIS-T, using transportation networks composed of complex properties associated with their multi-modal nature, different logical view and one-to-many relationships among vector-typed features in transportation (Butler

Table 1. General Aspect of Remotely Sensed Imageries for Transportation Application.

Type	Potential Application of Remotely Sensed Imagery in Transportation
Landsat ETM+	Large area emergency response and evacuation planning
SPOT HRV	Mapping background data such as population concentrations and environmentally sensitive areas for toxic waste transport routing and emergency response
IRS-C	Transportation infrastructure assessment and monitoring
IKONOS	Near real-time monitoring for road conditions and land cover changes Identify alternative transportation routes
Radarsat	Identifying potential natural hazard areas that may threaten transportation links

※ Partly cited from Foresman (1999(a)).

and Dueker, 2001). While, traffic modeling for transportation planning, followed by determination of TAZ and network topology building, can be processed as following steps; trip generation for trip rates based on mainly demographic coverage, trip distribution typically using the gravity model, mode selection related to with decision variables such as travel time, cost, or transfer, and trip assignment (Choi and Lee, 1997).

Further, in transportation problems, remotely sensed data would be effectively utilized to stimulate comprehensive and sustainable transportation networks and avoid mitigation and estimate impact costs through ecologically and socially sound designs. While, there have been performed researches concerned remote sensor data uses: automated transportation features identification, classification, and extraction and change detection approach for traffic impact analysis. In these days, ortho-photo or space-borne imageries have been utilized in transportation problems as following cases: ancillary base image for road network building, land use classification, or TAZ selection. Despite, it seems that remotely sensed imagery has not been effectively utilized in this traffic modeling process for transportation planning. Even in RS-T of NCRST program, transportation problems are somewhat limited scopes like infrastructure, monitoring, or impact assessment, as mentioned before.

In this study, it is distinguished transportation reference planning from general transportation planning, because this study is not somewhat different from GIS-T. Normally, processed results by transportation planning or traffic modeling are directed to handle actual transportation features such as road in a given database, according to transportation data model; whereas, results extracted from transportation reference planning used in this study would be quantitatively provided useful and referential information, for transportation analysts rather than supporting information for conventional traffic modeling of GIS-T. In additions, main data sets in transportation reference planning in this study are high-resolution satellite imagery, not vector-based transportation layers or databases.

While, since late 1990s, this approach has been intensively studied until these days. And this kind of attempt is sometimes categorized into RS-T (Remote Sensing in Transportation). The main goal in this study is to design and implement some useful extensions for quantitative information extraction for transportation reference planning, all aspects in RS-T are not covered, though.

One-meter high-resolution of IKONOS color imagery covering Namyangju-city, nearby metropolitan Seoul, Korea, was used in the test study for three kinds of extensions implemented in GIS development environment: Traffic flow estimation per link and block units and Urban Rural Index, and Accessibility index. While, site selection using KOMPSAT EOC imagery in the whole coverage is performed.

2. Study Area and Data Sets

One-meter high-resolution color imagery of IKONO was used in the test study, Namyangju-city (Fig. 1(A)).

KOMPSAT EOC imagery, superimposed with main road layers extracted from Korean standard digital map sets scale of 1:25K, was processed as a kind of site reference image (Fig. 1(B)). For this image, 9 sub-scenes in 2000 and 2001 were used and geo-rectified (Lee *et al.* (2002(a)).

Fig. 2(A) represents a land-use map, digitally complied with scales of 1:5K and 1:1K, covering the same area in Fig. 1(B). These data sets were originally produced in national thematic mapping program by KRIHS, 1999, one of products in NGIS program. Normally, land-use thematic map is one of influential information for transportation planning processes. Site selection such as spatial factor analysis can be

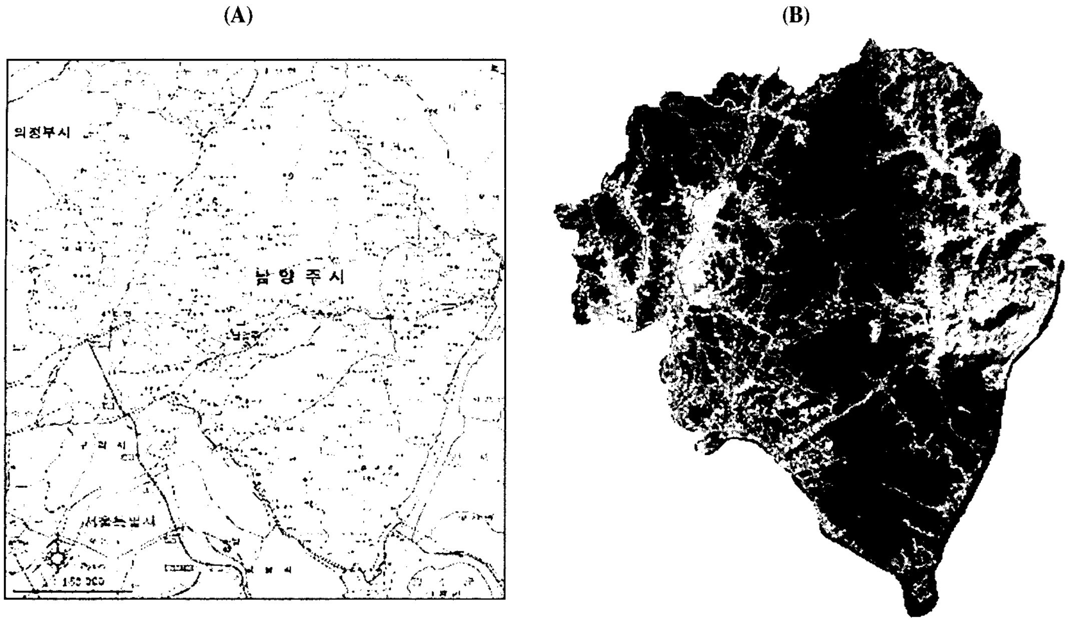

Fig. 1. (A) Test study area for transportation reference planning in this study. (B) KOMPSAT EOC imagery (complied scene using 9 imageries obtained in 2000 - 2001) for the same area, with main road layers, from NGI 1:25K digital map.

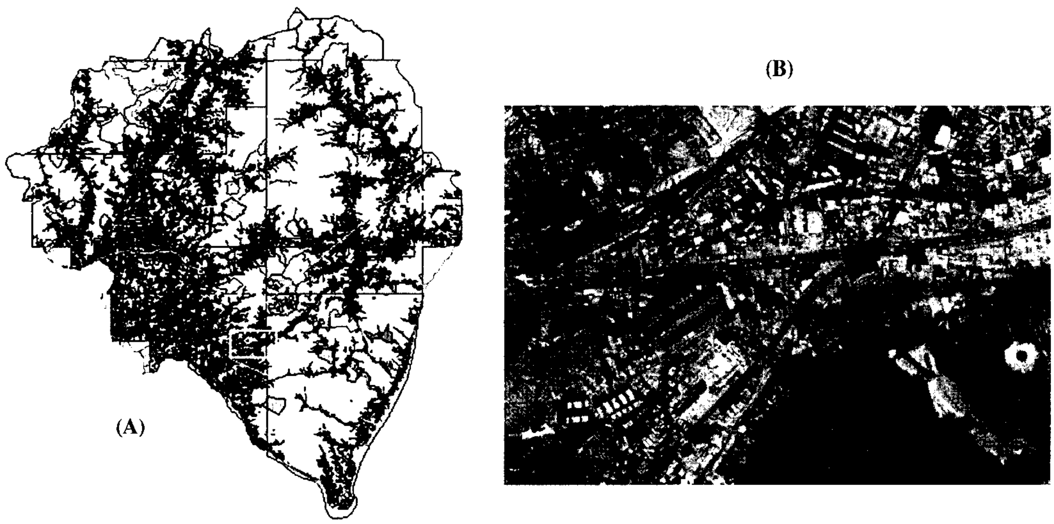

Fig. 2. (A) High-resolution imagery coverage in Land-use thematic layers (Lee *et al.*, 2002(a)).
(B) Sub-scene of IKONOS 1 m color imagery using in the study, applied to three types of transportation indices, implemented in this study.

performed using this data. From this data, target area for transportation reference planning can be determined (Lee *et al.* (2002(b)). In this area, it is shown that road network is expanded along urban site. In Fig. 2 (B), geo referenced IKONOS imagery, acquired in March 2001 represents the portion of the whole test area.

3. Some Indics for Transportation Rerference Planning

1) Estimation of Transportation Flow (TFL and TFB)

Transportation Flow (TF) is one of fundamental information in most transportation problems. In transportation system, TF can be directly obtained by using real-time sensing instruments and wireless communication.

Sensor information obtained at traffic sites collects at host center, and then they are processed under GIS-T or transportation monitoring system. However, using satellite imagery, it shows other procedures: data pre-processing, selection of analysis zone, and average traffic flow estimation in that area. In this case, processing results is not traffic flow information, at real-time in a certain sites, due to spatial resolution and temporal resolution of imagery data. In this study, it is designed that traffic flow estimation can be computed in two modes: link and block. As for link and block, they correspond road segment in arc or road in connecting multi-link structure similar to GIS-T approach and analysis zone in polygon, respectively.

At the following simple formulation of Eq. (1), TFL and TFB were implemented under ArcView® development environment using Avenue.

$$TFT = \frac{\text{no. of vehicles}}{\text{length of link}} \times \text{ave.speed of vehicle type}$$
$$TFB = \frac{\text{no. of vehicles}}{\text{area of block}} \times \text{ave.speed of vehicle type} \qquad (1)$$

Fig. 3 (A) and (B) represent user interfaces and dialog boxes for variable calibration of TFL and TFB, respectively. In these extensions, some databases in geometric features and their attributes are required: road layers represented as center-lines and road boundaries, road link, and administrative districts. Other input value such as number of vehicles in dialog box can be directly readable ones from satellite imagery. As for average speed, it is tentatively used as user defined value. But, it can be automatically accessed into this extension, just if transportation databases were already built.

Using these extensions, user can acquire average traffic flow estimation at a certain road or block area. These results can be stored as quantitatively referential information for transportation planning.

2) Urban Rural Index (URI)

As the second extension for transportation reference planning, Urban rural index (URI) was designed and

(A) (B)

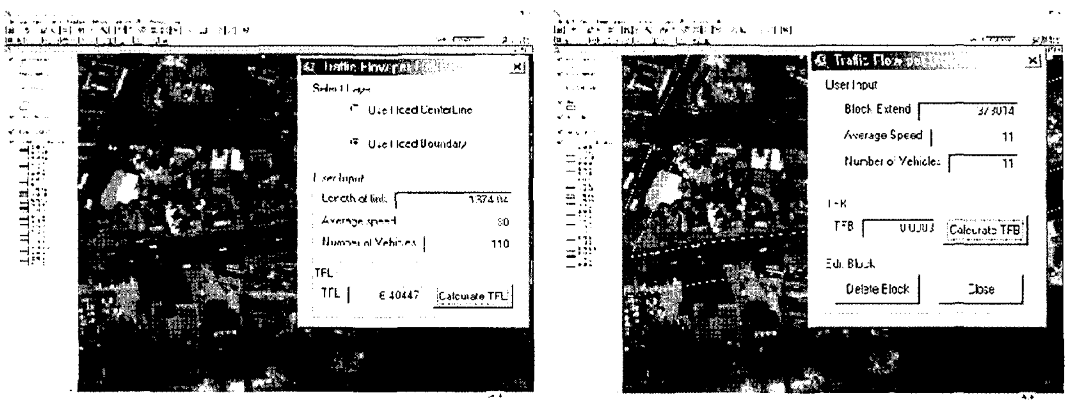

Fig. 3. TFL/TFB implementations: (A) User interface of TFL estimation. (B) User interface of TFB estimation.

implemented in this study. Actually, basic concept of URI was proposed by Foresman (1999(b)), shown in Eq. (2).

$$URI = R * D$$

$$R = (\frac{L}{S}) * (\frac{W}{S}) * (\frac{L*W}{A}) \qquad (2)$$

$$D = \frac{P}{A}$$

where URI: Urban Rural Index, R: Road density, D: Population density, L: Total road length, S: Number of link, W: Road width, A: Area, and P: Number of population.

Among these variables, most values in dialog box at Fig. 4 can be used to access database attributes linked in this extension, at the time of selecting URI zone by user. However, W can be determined from high-resolution imagery.

In this extension, multiple road widths are used, because most district area is composed of complex road network system, showing various road width. In user side, one interactively selects area of interest or traffic analysis zone. If chosen a certain zone, population attribute information is automatically linked, and area information, total length of road link and number of link

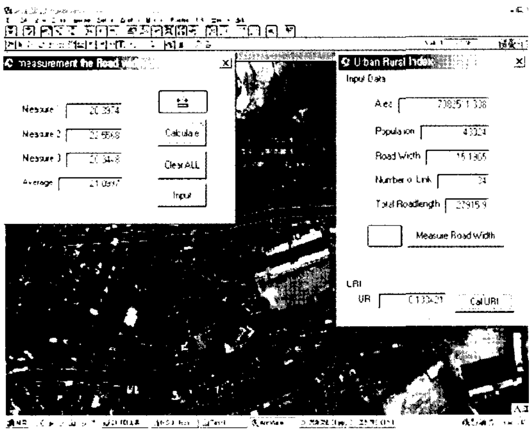

Fig. 4. Dialog boxes in user interfaces for URI computation: Road width measurement and URI estimation using multiple variables.

in this zone are computed in this extension, associated with concerned databases.

In transportation planning, results by URI at a target area can be interpreted as urban-rural characteristics; furthermore, this can be applied in selection of traffic analysis zone and in traffic modeling. Therefore, URI with results of TFL/TFB can be considered transportation indices for transportation reference planning.

3) Accessibility Index (AI)

It is known that 'accessibility' is an important element in analyzing the efficiency of a transportation system and its planning process. Term of accessibility is normally used to measure the ease of residents going from one place to another. For this index computation, there are some distinctive methods of deriving various accessibility indices for the measurement of an accessibility level. However, this term shows the limitation by lack of the generality for applying in different situation, and several approaches are available (Lai and Lilian, 2000).

Among several expressions for computation of this accessibility, the following one extracted from the gravity model is used and implemented. In this study, the formulation for this index was initially proposed by Javier and Gabriel(1999).

$$A_i = \frac{\sum_{j=1}^{n} (T_{ij} M_j)}{\sum_{j=1}^{n} M_j} \qquad (3)$$

where A_i = the accessibility of node i, T_{ij} = travel time through the network of the node i and the centroid js of polygons touched, and M_j = the mass(population) of the destined centroid.

Fig. 5 (A) and (B) represent the processing logic and user interface within this extension, respectively. From Fig. 5(A), user selects AOI(Area Of Interests) in extents,

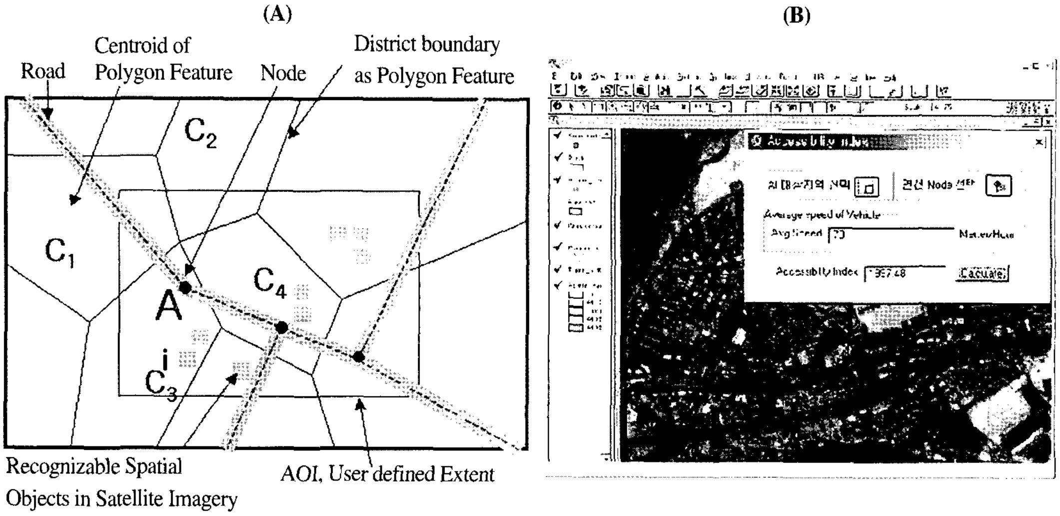

Fig. 5. (A) Explanatory diagram for basic concept of accessibility index.
(B) User interface for AI estimation, with selected nodes.

and then contacted or intersected polygons are automatically determined in this extension. As for road network system, each road segment is connected under node-link structure. As one of computation variables, centroids such as C1 to C4 of each touched or intersected polygon in Fig. 5(A) are then computed, and distance between road segments traversing node in interests, and distance values between several polygon centroids and other nodes are also computed. As for mass information, it can be replaced with population of districts, being touched or intersected with road system.

However, travel time is not direct input variable in this extension, because this program does not link with real-time or near real-time transportation data acquisition system. Therefore, user insert value of average speed of vehicles on selected road, and then travel time can be obtained from distance previously computed. Using high-resolution satellite imagery, user can recognize spatial features or urban objects nearby road system, which he/she wants to estimate accessibility index, and accessibility index surrounding urban objects of interests can be collected and summarized for further study.

In transportation planning, this index can be utilized to extract quantitative information representing characteristics between specific urban sites and road network system, at the nodes for road segments.

4. Conclusions

Among applications of remote sensing, transportation field has a rather short history. However, since commercial high-resolution satellite imageries have been available and then is regarded as an important data source in transportation field, application of this domain has been one of intensive research area, as RS-T. Though transportation problems are somewhat complicated task, and composed of lots of units, extraction of referential quantitative information for transportation planning is main purposes in this study.

For this task, some extensions for extraction of these indices were designed and implemented under GIS development environments. In TFL/TFB, user can obtain quantitative results on traffic flow estimation using high-resolution satellite imagery. Whereas, URI extension provides urban characteristics related to road system, being considered one of important factors in transportation planning. Lastly, AI extension helps to obtain accessibility index on nodes of road segments and surrounding district area touched or intersected with the road network system, and it also provides useful information for transportation planning problems. While, these extensions for transportation reference planning do not contain GIS-T databases building wireless communication modules, and sensor acquisition system on-site, so that usability of remotely sensed imagery in this problem is emphasized. However, if those are added in these extensions, practical applicability will be improved, and can be apply in transportation management or monitoring system.

Currently, validation of these implementations is testing as actual local government problems, in consideration to other concerned databases in GIS environment, because this is not included in conventional functionalities in GIS-T. Conclusively, these kinds of approaches in transportation reference planning will broaden new remote sensing applications, as a part of RS-T, especially related to the utilization of satellite imagery provided from KOMPSAT 2.

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