Developing a Time-series Visualization Technique using a Temporal GIS Database for Urban Growth Simulation

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This study aims to design and develop an urban growth simulation using a temporal GIS database consisting of different forms of spatial data for analyzing urban sprawl phenomena in Seoul Metropolitan Area and Gyeonggi Province. We analyzed the characteristics of spatial data and selected appropriate scales and transformation methods to establish consistent database contents. For this, we first developed and constructed time-series visualization techniques with a temporal GIS database and satellite images and topographic maps of the last 80 years to analyze variables which affect urban growth. The variables are roads, transportation systems, land use, population, and urbanization etc. Then, we implemented the visualization methods for various socio-economic and physical variables using the constructed temporal GIS database. We expect that the proposed technique shall be used in many different purposes such as urban sprawl monitoring, river basin analyses, environmental impact analyses, and hydrological modeling. In addition, while being the basic information for sustainable urban growth and urban land use planning, the developed temporal GIS database can be used in calibrating the current urban model and developing future urban growth models as well.

Keywords: urban growth simulation, temporal GIS databases

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1. INTRODUCTION

1.1 Research Purpose and Background

Urban areas in industrialized countries have been confronting many problems such as over-population, traffic jams and environmental problems. Thus, it is crucial to understand how urban areas have been developed in the past and how they will be growing in the future for solving such urban problems.

The Seoul Metropolitan Area (SMA) of Korea has been experiencing rapid population growth and expansion. In order to analyze the long term urban growth pattern and its impacts on nationwide physical and socioeconomic environment, a temporal GIS database is necessary (Acevedo et al. 1996: Clark et al,. 1996, Kang & Park, 2000). The development of a temporal GIS database shall be employed to calibrate the current urban models, and to generate future urban growth models as well. Also, it can be used for many different purposes such as urban sprawl monitoring, river basin analysis, environmental impact analysis, and hydrological modeling. Moreover, it will become basic information for sustainable urban growth and urban land use planning.

In this study, we first develop and construct a temporal GIS database to develop an urban growth simulation and to analyze variables which affect urban growth (ex. roads, transportation systems, land use, population, urbanization and etc). Various satellite images and topographic maps collected for the last 80 years are also used in the study. Secondly, we develop the visualization methods for various socio-economic and physical variables using the constructed temporal GIS database.

1.2 Data Source

The geographical scope of this research is the SMA in Korea that includes Seoul and some parts of Gyeonggi Province. For the research purpose mentioned above, we analyzed existing maps such as topographic maps, digital maps, and satellite images collected from various organizations. The National Geographic Information Institute in Korea provides many types of thematic maps which include metadata information: the methods, accuracy, consistency, date and scale. We also collected related maps from domestic governmental institutions such as the Ministry of Environment, the Ministry of Public Administration and Security, The Institute of Gyeonggi Development, the Office of Gyeonggi Province, and other related research and academic institutions. In order to maintain the consistency for the different spatial and temporal ranges, databases for the study area were constructed in a single unit frame rather than a multi-tile style. Paper maps were digitized or scanned and different data formats were converted. Socio-economic data integrated with administrative data by periods were also stored in the database system as attribute data. The constructed temporal GIS database was organized for further analyses in five time periods; 1920, 1960, 1970, 1980 and 1990. Then, for each year, the following themes were analyzed:

- Urbanized areas (residential areas), agricultural areas, and other areas
- Transportation networks

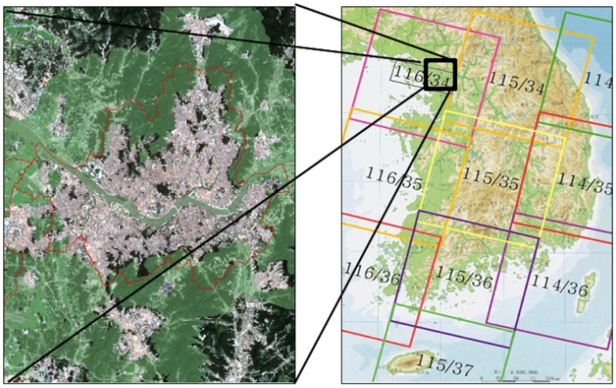
(roads, highways, railways etc.)
- Water systems
(River, ocean, lakes and etc.)
- Restricted Development Area
- Digital Elevation Model and contour line
- Administrative areas
(Provincial and municipal units)
- Land use/cover
- Population for Administrative units

We then developed a computer simulation, which visualizes the changes of urbanization patterns, socio-economic factors, and land uses.

2. THE PERIODIC SPATIAL DATA AND CHARACTERISTICS ANALYSES

2.1 The Geographic Scope of the Study Area

The area scope of the study is the Capital region including Seoul City, Incheon City and Gyeonggi Province. The total area for the study is around 15,000km^2 (115 km×156 km) as shown in Figure 1. Although some islands on the west coast are located within the study area, they were excluded from this study because of their less active growth and difficulties in data acquisition.



〈Figure 1〉 The study area: Seoul City, Incheon City, and Gyeonggi Province

2.2 The Selection of Spatial Data

We have reviewed related literature on the selection of appropriate spatial information to construct the GIS database for urban growth simulation. Based on the findings in the previous studies, we selected variables known to affect urban growth; variables such as urbanized area, land use/cover, transportation networks, water systems, Restricted Development Zones, administration areas, statistical information of socio economic factors and DEM.

In particular, information related to the urbanized area is the base fundamental information for analyzing the various types of spatial patterns of urban growth while land use/cover and transportation data are factors that directly influence the growth of urban areas. Other related information was used as factors that control or restrict the urban growth under the frame of administrative information such as population and other social-economic information.

2.3 Acquisition of Thematic Spatial Data and Characteristics Analyses

Thematic spatial data from 1900 to 2000 were collected as described in Table 1. The information of the collected data such as date of map generation, accuracy, contents, and spatial scope, were analyzed to produce the thematic base data for the study and the following shows the key characteristics of those maps and data.

2.3.1 Topographic maps

Topographic maps at 1:50,000 scales were collected from the year 1890. Since 1:250,000 scaled maps had not been created until the 1960's they were collected after that date. One to two hundred and fifty thousand (1:250,000) scale maps by years were used for constructing the base GIS database. It should be noted that some old maps created before the 20th century, usually for military purposes, were not accurate enough to be used for this study. Maps at 1:250,000 scales were used for constructing transportation networks and administration data.

〈Table 1〉 Types and years of the collected maps

	Database	*Years*
Topographic Maps	Topographic maps (1:50,000)	1890, 1920,1960, 1970,1980,1990's
	1:250,000	1961, 1965, 1973, 1976, 1986, 1991
Thematic Maps	Restricted Development Area Map (1:50,000)	1974
	Land use map (1:250,000)	1994
	Urban planning map (1:50,000)	1997
	Road network (1:200,000)	1998
Digital Maps	Digital topographic map (1:5,000)	
	Digital topographic map (1:250,000)	
Digital Data	Digital Elevation Model (30m) in Gyeonggi Province	1990's
Statistical Data	Town level population data	1920's ~ 2000
Satellite Images	LANDSAT MSS	1972, 1979, 1981
	LANDSAT TM	1985, 1988, 1992, 1996, 2000

2.3.2 Thematic maps

The maps of Restricted Development Zone (RDZ) at 1:50,000 scales were created based on 1:50,000 topographic maps and used to archive RDZ information into the GIS database because of the high compatibility between their formats. Land use maps at 1:250,000 scales existed only in 1972. Thus, scaled land use/cover maps in other years were used instead to create the GIS database.

2.3.3 Digital topographic maps and digital elevation data

Digital maps at 1:5,000 and 1:25,000 scales were totally compatible with paper maps in their characteristics and contents. Digital maps were used, especially, for creating a digital elevation model in this paper.

2.3.4 Satellite images

Satellite images are acquired from satellite orbits around the earth. Using it's sensors, a satellite captures energy from the earth's surface and the acquired data are transferred as digital images. Since satellite images are produced with computational processes they are easily converted and integrated with spatial information. LANDSAT data since 1972, Multi-Spectral Scanner (MSS) images at resolution 80m and TM images at resolution 30m were available to us. We collected three MSS images for 1972, 1979 and 1981 and five TM images from '85, '88, '92, '96, and 2000. These satellite images were used for generating land use/cover data and urbanized area information.

2.3.5 Population statistics

Urban growth is related to many socio-economic factors, particularly the population of the area. The population data were collected in every 5 or 10 years since 1920. The Korean Census Bureau has been archiving various socio-economic data since the 1950's. We collected and converted these socio- economic data into the GIS database and utilized them for further analyses. Table 2 shows the list of data used to construct a thematic database.

〈Table 2〉 The list of data for constructing thematic database

Thematic data	*Base data*	*Subsidiary data*
Urban area	Topographic map	Satellite images, land use map
Land use/cover	Satellite images	Topographic maps, land use map
Agricultural and other areas	Topographic map	Satellite images, land use map
A water system	Topographic map	Road network,
Restricted Development Zone	Restricted Development Area	
Digital Elevation Model	Digital Topographic map	Topographic map
Administration Unit	Digital Topographic map	Digital Data
Population Statistics	Census	

3. CONSTRUCTION OF A TEMPORAL GIS DATABASE

3.1 The Structure of a Temporal GIS Database

A Temporal GIS database of the study area was used to analyze patterns and characteristics of urban growth in the past, and to calibrate and perform the prediction model of urban growth. The structure of the GIS database for such various purposes was designed to satisfy the following basic requirements:

· The temporal GIS database should be developed in the largest scale forms as possible.

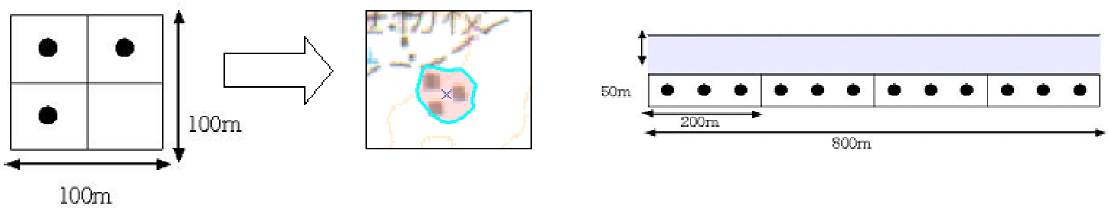
- · Data should be developed in the most appropriate forms meeting the required accuracy and the data model.
- · Time series data should be in the same coordinates system.
- · Thematic data should maintain consistency over time.
- · Developed time series data should be easily converted and modified.

Spatial data should be connected to attribute data such as population statistics. To satisfy the conditions mentioned above, temporal GIS databases should be capable of integrating various forms of data models such as vector, raster, image, and statistical data. Also these databases were designed to be the structure of object-relational spatial databases that support continuous forms of data.

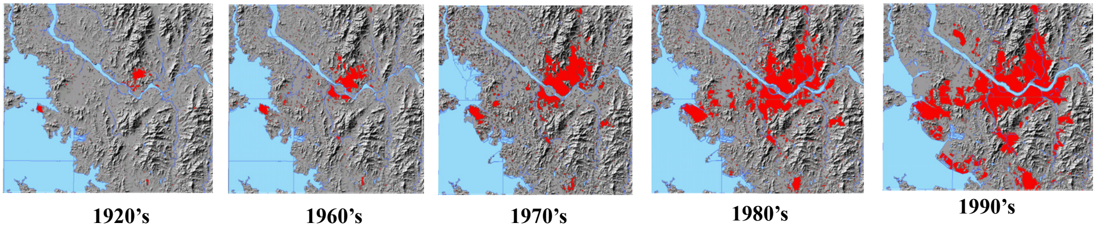
3.2 Construction of the Temporal GIS Spatial Database

Urban regional data, considered one of the most important data in the temporal GIS database, represents urban land use generated by human activities such as residential cluster settlements, commercial and industrial districts, and various artificial structures. While the USGS defines the residential area based on housing density (at least 3 in 10 acres), the standards for defining urbanized regions by land uses are not explicitly established in South Korea. Therefore, urban land-uses were categorized into sub-zones such as residential areas, built-up areas and environmental facilities, which were integrated into the urbanized areas.

From topographical map interpretation, we defined the residential areas with 100m × 100m grids as the minimum mapping unit and the housing density as more than 3 households (see Figure 2). Also the residential areas were included over 800m and 12 household buildings. The built-up areas were defined as red-colored districts for high density areas of buildings. Figure 3 shows the time series data of urbanized areas.

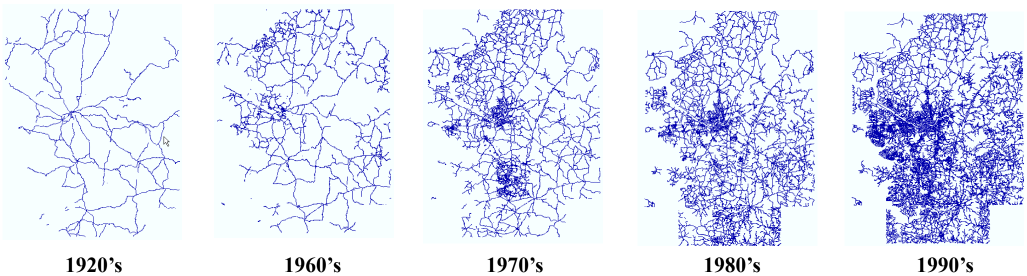


⟨Figure 2⟩ Generating boundaries for residential areas+



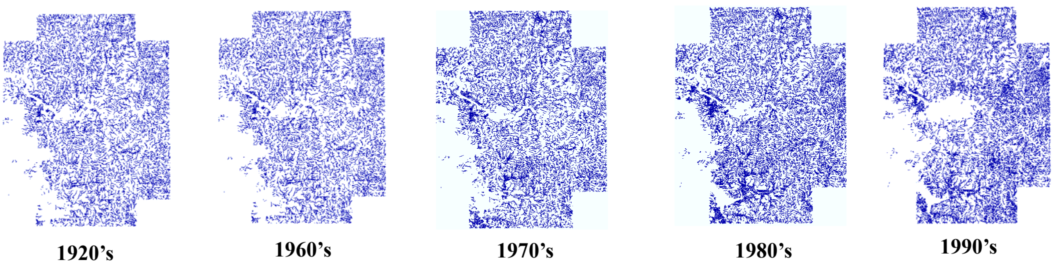
〈Figure 3〉 Time series data of urbanized areas

The time-series transportation data were created using road and train networks and further classified according to sub-types. The different types were then input into the database using unique codes to facilitate visualization and selection. Transportation data by years are shown in Figure 4.



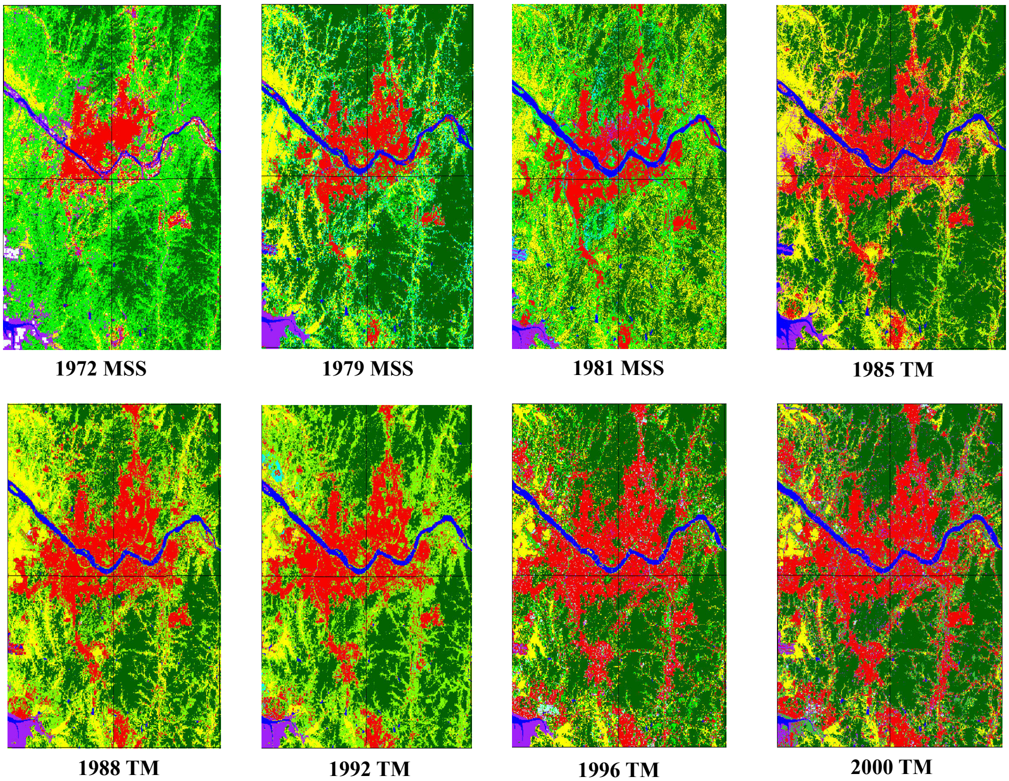
〈Figure 4〉 Time series data of transportation (Roads)

Hydrosphere data include the seashore, rivers, reservoirs, lakes, swamps, and salt-pans. They work as natural constraints that prevent the spread of urban areas. The constructed hydrosphere data are displayed in Figure 5.



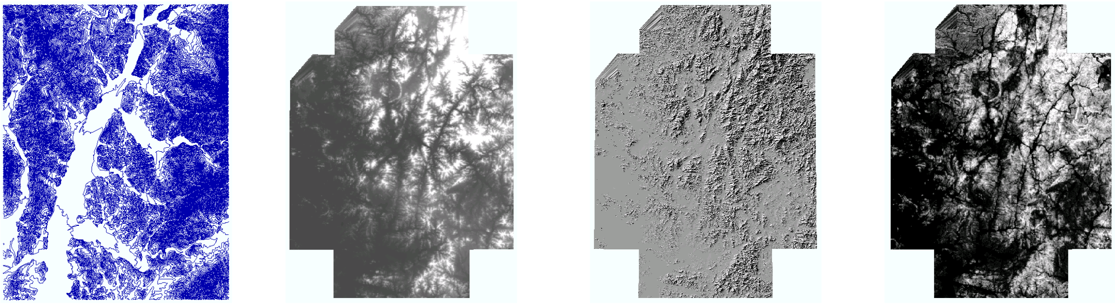
〈Figure 5〉 Time series data of hydrosphere

Administrative districts data were used to identify spatial distribution and characteristics of urban areas, and to display social and economic data such as population. The land cover maps were used as a base data for exploring the present conditions of earth surfaces and developing future plans for local areas. Producing the land cover maps required gathering geographic information from satellite images. Such processes as exporting, building, and managing the land cover information were needed as well. LANDSAT images since 1972 were used in this study. We used multi-spectral scanner images at resolution 80m and 30m resolution TM images. We collected three MSS images in 1972, 1979 and 1981 and five TM images in '85, '88, '92, '96, and 2000. These satellite images were used for generating land use/cover data and urbanized area information. The constructed land cover maps using satellite images are shown in Figure 6.



〈Figure 6〉 Time series data of land cover

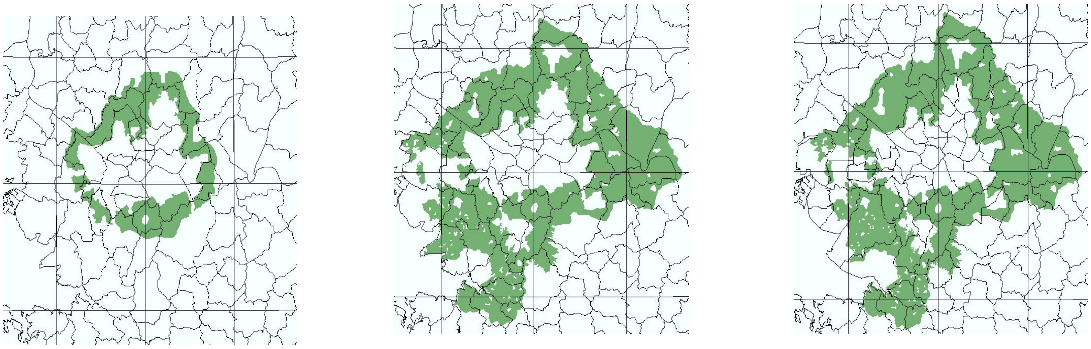
Gradient maps were built by extracting contours and layers from digital topographic maps, interpolating them in TIN (Triangulated Irregular Network), and then transforming into DEM (Digital Elevation Model) or a percent form. The DEM were used as the slope descriptions for the study (Figure 7).



1:25,000 contour **DEM** **Shaded Relief Image** **Slope**

〈Figure 7〉 DEM (Digital Elevation Model)

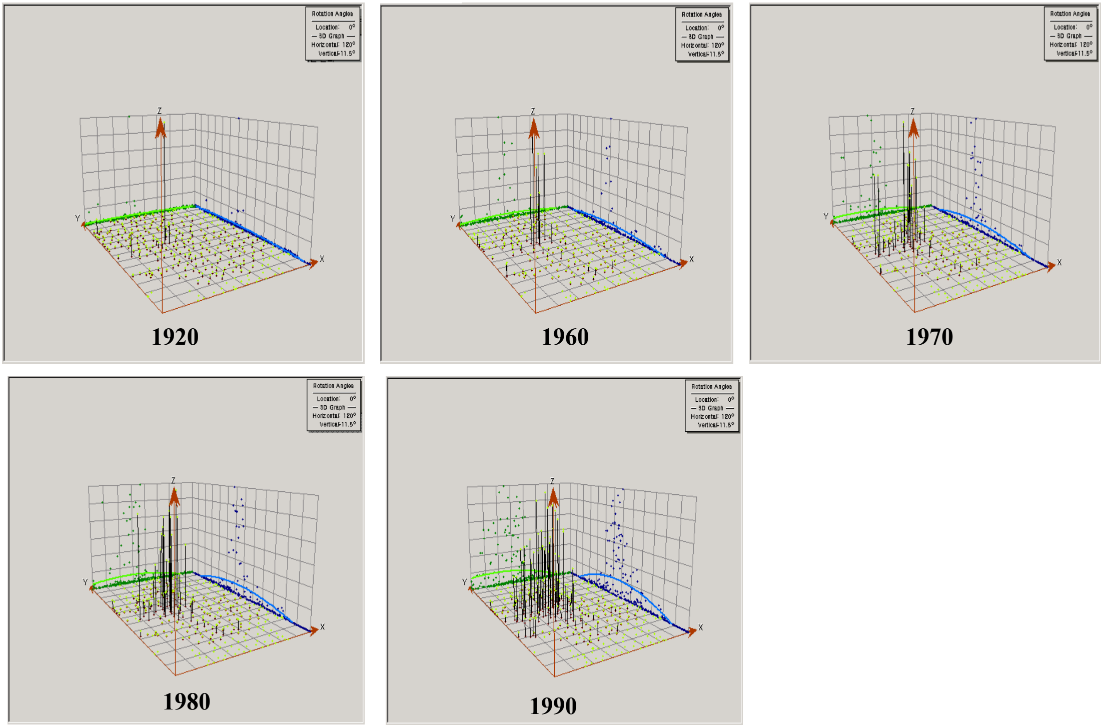
In Korea, the development of a restricted zone (or green-belt system) has been established and maintained since 1971. We collected the green-belt data from it's inception to the present time (Figure 8). The green-belt data along with hydrosphere data can be used as factors in studies with a purpose to prevent urban growth.



1972 **1981** **1995**

〈Figure 8〉 Time series data of the green-belt

Population data has been collected approximately every 5 or 10 years since 1920. The Korean Census Bureau has been archiving various forms of socio-economic data since the 1950's. We collected and converted these socio-economic data into the GIS database for further analyses. Figure 9 shows a three-dimensional view of the population density of some selected years.



〈Figure 9〉 Time series data of population density

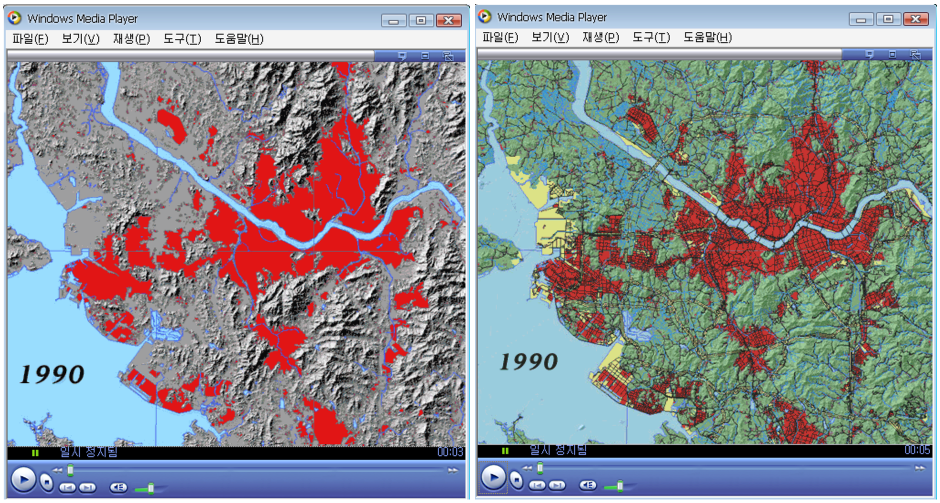
4. VISUALIZATION AND ANIMATION OF A TEMPORAL GIS DATABASE

4.1 The Visualization

The process for visualization is defined as the creation of continuous images that are converted from simulation data for better human perceptions (Haver and McNabb, 1990). One can be better aware of data through interactive communication between maps and visual perception. For analyses and representation of spatial data changing continuously over time, the dynamic animation maps are more efficient than 2-dimensional static maps (Acevedo, W and P. Masuoka, P, 1997; Bell. C, W. Acevedo, and J. T. Buchanan, 1995; Crawford, J.S., W. Acevedo, T. W Foresman, and Prince, W., 1996; Masuoka, P., W. Acevedo, S. Fifer, T.W. Foresman, and Tuttle, 1996).

4.2 Generating the Animation Maps

Since animation maps are implemented by frame units based on raster format, raw data built in vector (Arc/Info file format) are converted into raster. Animation maps were generated using a raster-based visualization and interpolation tool (Animation Shop3 of Jasc Software). Figure 10 displays animation snap shots that represent the processes of urban growth and the development of transportation networks, the shoreline, and land use changes. In addition, animation maps are also capable of displaying changing aspects of legal provisions and their relationships with urban areas when overlaid with time series green-belt data.



〈Figure 10〉 Time series animation snap shots for the urban growth simulation

5. CONCLUSIONS

In this study, we designed and developed an urban growth simulation by using a temporal GIS database containing various forms of spatial data required for analyzing urban sprawl phenomena in Seoul Metropolitan Area and Gyeonggi Province. We analyzed the characteristics of various spatial data available and selected appropriate scales. Transformation methods were used to establish consistent database contents.

We first developed and constructed time-series visualization techniques with a temporal GIS database in order to analyze variables which affect urban growth (ex. road, transportation system, land use, population, urbanization and etc.). We utilized various satellite images and topographic maps collected during the last 80 years. We then implemented the visualization methods using the constructed temporal GIS database including both the socio-economic and physical variables.

We expect that the proposed methods can be used for many different purposes such as analyses of urban sprawl, river basins, environmental impacts, and hydrological modeling. Also, they can be used as the basic information for sustainable urban growth and urban land use planning, and in calibrating the current urban models and generating future urban growth models as well.

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