AN INTEGRATED URBAN SYSTEMS MODEL WITH GIS

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The main purpose of this paper is to explore a possible integration for the entire transportation modeling procedure -- from data inventory to future demand forecasting -- by implementing integrated land use and transportation models with a geographic information system (GIS). In order to make an integrated, procedural modeling system possible, Land Use and Transportation modeling system with GIS (LUTGIS) has been developed and its application to the city of Seoul is presented in this paper.

There are four sub-systems in LUTGIS: (1) a data inventory system, (2) a traffic analysis zone generation system, (3) an integrated land use and transportation modeling system, and (4) a graphic user interface (GUI) system. Since the main target of this paper is to explore a possible way to create a viable system, LUTGIS integrates currently available and user-friendly computing technologies. For both transportation planners and administrative decision-makers, such an operable system is very desirable for sharing information so they may arrive at a consensus through the use of LUTGIS, an integrated land use and transportation modeling system.

Introduction

The ceaselessly increasing number of trips on urban highways and major arterial roads have caused serious congestion and air pollution problems. Thus many transportation agencies have persevered in their efforts not only to alleviate such problems, but also to minimize social costs. However, the complex nature of such problems has strongly hindered transportation agencies' ability to consider an integrated framework, which combines land use and transportation planning. Both urban travel and land use are too strongly interrelated to be separately considered.

The Intermodal Surface Transportation Efficiency Act of 1991 (ISTEA) has stipulated that transportation planning be a systems approach considering both environment and performance concurrently, requiring that planners consider transportation planning in conjunction with land use planning. ISTEA necessitates a more comprehensive, multimodal, systems management approach to transportation planning. As a result, many metropolitan planning organizations have considered both land use and development in their long term transportation planning as well as short term transportation improvement programs (FHWA, 1998; Kaiser et al., 1995).

For many years, transportation planners have attempted to develop integrated land use-transportation models in various modeling frameworks. However, there have been few successful implementations of the integrated, operational land use-transportation model due to some critical problems, such as lack of necessary transportation network and socioeconomic data, labor-intensive data operation, and difficult model formulation. In order to overcome such problems, this study has explored GIS technologies, which can possibly support the development of an integrated, operational land use-transportation model.

Objectives of the Study

In spite of the noble idea of integrating land use-transportation models to support the complicated decision making procedures of transportation planning, few systems have been implemented in large urban areas because of complicated models, difficult data acquisition, and improper computing technologies. Therefore, the main concern of this study is to develop a possible way to integrate land use-transportation models in a systematic framework by adopting GIS technologies so that transportation planners can simulate the interaction between land use and transportation activities in urban areas. The study objectives are as follows:

- reviewing the existing land use-transportation models,
- integrating land use-transportation models with a GIS, as the system integrator including temporal dynamic impacts of transportation improvements and land use, and
- evaluating and validating the system with Seoul data.

Integrated Land Use-Transportation Modeling

The main purpose of developing a land use-transportation model is based on the idea that urban structure can be forecasted as well as controlled by calibrating the current urban structure and determining the size and shape of the future urbanized area. Since Lowry's opening in the field of urban models in 1964, many transportation planners have been inspired by the idea that they could construct a feasible way to simulate an entire urban system. In fact, many land use-transportation models have been developed as a whole or part of an integrated urban model, and they have allowed a more systematic approach that explains urban structure.

A combined land use-transportation planning approach primarily requires iterative and integrated land use-transportation models (Kaiser et al., 1995), and those models have been continuously developed and empirically applied for several decades (Webster, Bly, and Paulley, 1988; Wegener, 1994; Southworth, 1995). In the United States, some examples of integrated land use-transportation models include BOYCE (Boyce, 1986; Boyce, Tatineni and Zhang, 1992), CATLAS/NYSIM (Anas, 1983, 1992), ITLUP (Putman, 1983, 1991), KIM (Kim, 1989), POLIS (Prastacos, 1986), PSCOG (Watterson, 1993), and CUFM (Landis, 1994). Also, there are some applied models in European countries such as AMERSFOORT (Floor and de Jong, 1981), DORTMUND (Wegener, 1982, 1996), LILT (Mackett, 1983, 1991), MEPLAN (Echenique et al., 1990; Hunt and Simmonds, 1993), and TRANSLOC (Boyce and Lundqvist, 1987; Lundqvist, 1989). Both CALUTAS (Nakamura, Hayashi, and Miyamoto, 1983) and OSAKA (Amano and Abe, 1985) have been developed in Japan, and TRANUS (Barra, 1989) has been practiced in Venezuela. In addition, TOPAZ (Brotchie, Dickey, and Sharpe, 1980; Dickey and Leiner, 1983) has been applied in Australia as well as in the United States.

In spite of the progress, it is true that integrated urban models are still difficult to use due to critical problems such as insufficient data quality, inadequate model calibration, and incomplete documentation (Klosterman, 1994). Nonetheless, there has been a consensus among modelers that integrated urban models will perform a critical role for land use-transportation planning practice in the near future (Klosterman, 1994; Wegener, 1994).

GIS in Land Use-Transportation Modeling

Although many modelers agree with the fact that the most unique helper to stimulate urban models is the recent developments in the field of GIS (Batty, 1994 and 1992; Wegener, 1994; Harris, 1992; Heikkila, Kim, and Moore II, 1989), only few urban modelers tried to adopt GIS technologies in their models due to complicated technical problems. However, no one has doubted that a GIS will ultimately make large-scale urban models thrive again and that land use-transportation model integration will be intensively improved. In order to provide adequate functions for the integration of land use-transportation models, GIS technologies will primarily assist in identifying connectivity, contiguity, and proximity on a complicated urban transportation network. Basically, a GIS has the following functions which can support the development of an integrated land use-transportation model (Choi and Kim, 1995):

- visualizing and editing spatial data,
- managing aspatial databases which help traffic analysis zone (TAZ) generation,
- creating and editing transportation networks with topology, and
- analyzing spatial data using search and query tools.

First, a GIS can be a useful database management system which can display and edit spatial/aspatial data. Lewis (1990) also reports that a GIS is a dexterous database integrator. Because most of currently available GISs use relational database technologies, it is easy to understand that a GIS can be an effective data inventory system in land use-transportation modeling. Moreover, because many local and federal governments have constructed massive socioeconomic and transportation infrastructure databases, an integrated land use-transportation model can directly use those databases by adopting GISs. Because necessary data acquisition is one of the most critical problems for land use-transportation modeling, adopting a GIS will alleviate a great deal of data inventory problems.

Second, GISs can alleviate the difficulties of transportation network generation. For a land use-transportation model, generating a transportation network is essential. However, conventional methods require very time-consuming procedures. If a modeler desires to simulate a network in various ways by modifying an original network, conventional methods will be too slow to generate all the necessary networks for his/her models. Therefore, using a GIS as a network generator is very desirable in land use-transportation modeling.

Third, a GIS can be a successful spatial data analysis tool. A land use-transportation model produces a variety of outputs including future origin destination tables, link costs, volume per capacity (V/C) ratios, and so forth. Therefore, querying and searching functions are essential to analyze such abundant outputs in an efficient manner. Visualizing the results is the primary tool for spatial data analysis, and querying and searching functions are the secondary ones. In addition, it is obvious that an electronic map, which can be queried and searched, analyzes the outputs better than typical outputs of land use-transportation models, which are usually non-graphical, numeric forms.

GIS technologies are relatively new in transportation modeling. Thus, there would be more sophisticated ways to adopt GIS technologies in land use-transportation modeling. Nevertheless, it is clear that the described functions above are still valuable, and will greatly assist in the development of an integrated land use-transportation model.

Modeling Framework and System Design

The objective of system design is to integrate land use-transportation models in a systematic framework with the assistance of GIS. Basically, there are four important sub-systems that the proposed system should include: (1) a data inventory system, (2) a traffic analysis zone (TAZ) generation system, (3) an integrated land use and transportation modeling system, and (4) a graphic user interface (GUI) system. Figure 1 shows a possible schematic chart of integrated land use-transportation model.

At the beginning of the modeling stage, a functional GIS manages a data inventory system to relieve the labor-intensive data management problems which severely hinder the real practices of land use-transportation models. After constructing a data inventory system, a TAZ generation system is developed based on the adopted GIS, which maintains the constructed data inventory system. In order to generate reasonable TAZs, sophisticated zone generation algorithms need to be customized using computer programs, and the programs should be integrated in the GIS.

The created TAZs do not have connections from the newly created zones' centroids to the existing road network, which is maintained by the data inventory system. Therefore, the next task is to create zone centroids so that virtual links can connect the created zone centroids to the network. Another important task in this stage is that all sub-zonal[1] demographic and socioeconomic attribute data is to be summed after creating the centroids. To make such complicated functions available, the adopted GIS software and customized computer programs will work together not only to create an aggregated TAZ attribute tables but also to add virtual links between the existing road network and the zone centroids created. In fact, these procedures should be able to fulfill the TAZ generation processes automatically, manually, or both so that a user accepts the automatically generated TAZ system and the modified road network, or rejects the result to edit it manually or to re-generate a new TAZ system automatically.

[1] A sub-zone is an element zone of an aggregated zone. After a TAZ generation, the elementary zone is virtually merged into the aggregated zone and maintains its original data in the data inventory system for other uses in the system integration.

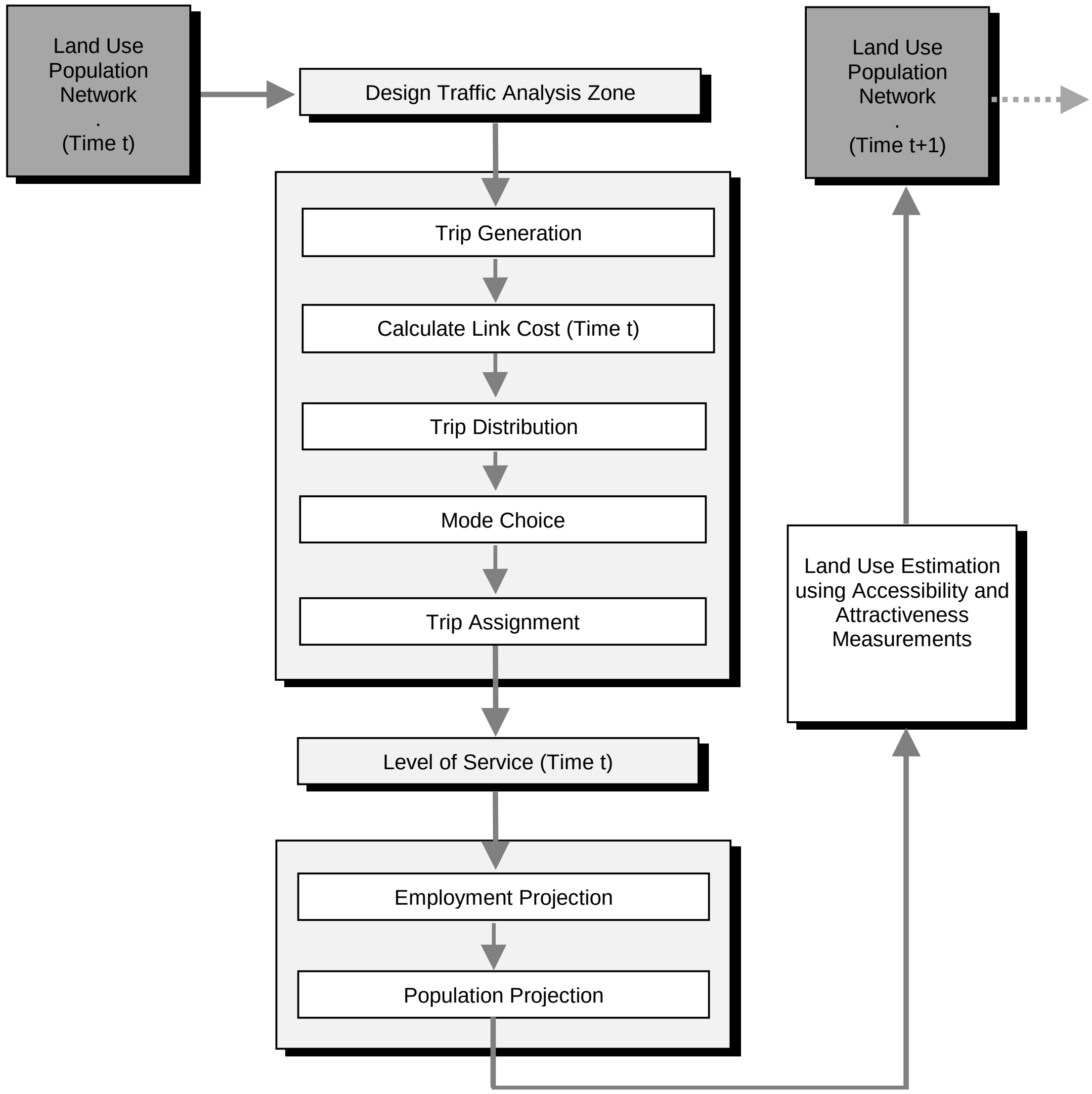

Figure 1. A Possbile Schematic Chart of Integrated Land Use-Transportation Model.

After generating TAZs satisfactorily, the following stage is the operation of mathematical land-use transportation models. In general, this stage consists of two parts; employment and residence allocation modeling and transportation modeling. From the system point of view, this stage requires that all necessary parameters for both mathematical models should be pre-specified. In order to make the operation easy, developing well-designed graphic user interfaces, which are usually more cognitive than text-based input-output, are necessary so that a user can conduct multiple operations effectively. The graphic interfaces allow users to input the required parameters and also understand current parameter settings in graphical sense. Also, the integrated system should allow users to have feedbacks from the operation of land-use transportation models. For this purpose, various visualization tools are required. Like many other transportation modeling systems, providing only text output is not enough to enable modelers to understand complicated motions of mathematical models that are integrated in the proposed system.

At the end of modeling stage, a user can query the results through a visualization sub-system, which is maintained by the proposed GIS with the assistance of customized computer programs. In the visualization stage, a user can carry out various types of queries. In addition, query results should be stored to compare with other outputs. Figure 2 shows a possible system design with a GIS.

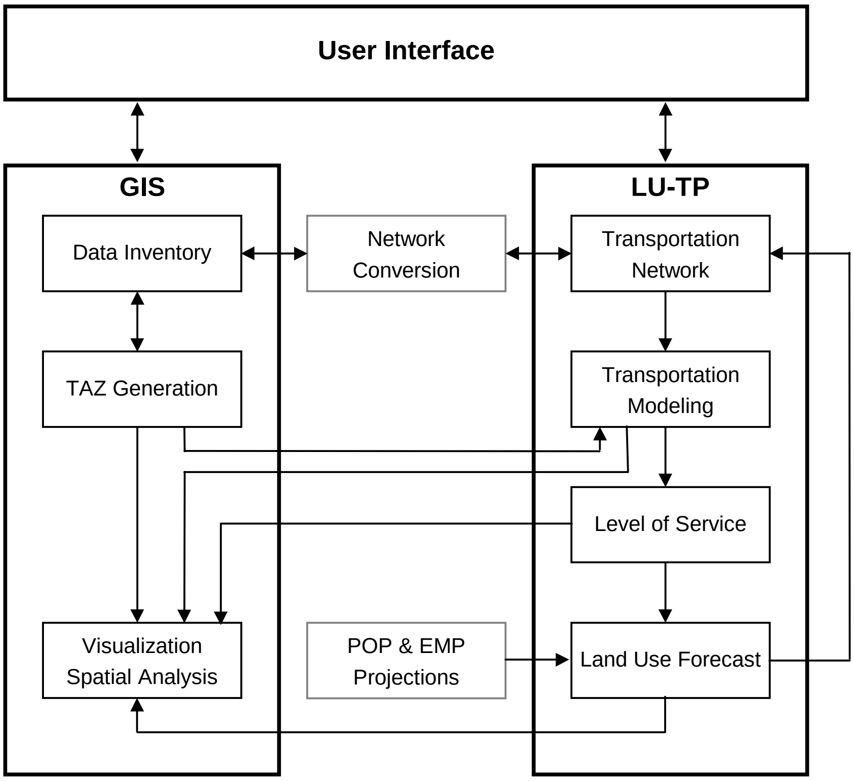

Figure 2. A Proposed System Design Using a GIS.

Depending on the modeling frameworks, a variety of modeling integration procedures can be considered. In this study, the five-step land use-transportation modeling framework is considered from the TAZ generation to the trip assignment model. Like many other conventional transportation models, the proposed modeling framework in this study also requires a series of decisions. To make reasonable decisions in each stage, the model should be arranged in careful manner by observing the data flow among sub-models. The concrete descriptions for the five steps are as follows:

❑ *Step 1: TAZ Generation*

The proposed five steps are initiated by the TAZ generation. TAZ design procedures follow steps shown in Figure 3. For TAZ generation, the following procedure is the summary of the TAZ generation (You, Nedovic-Budic and Kim, 1997a and 1997b).

1. Building GIS database,
2. Constructing topological relationship,
3. Creating initial partition using agglomerative clustering
4. Optimizing the initial partition using iterative partitioning,
5. Conducting spatial data analysis,
6. Inputting the result into GIS, and
7. Performing visualization/evaluation.

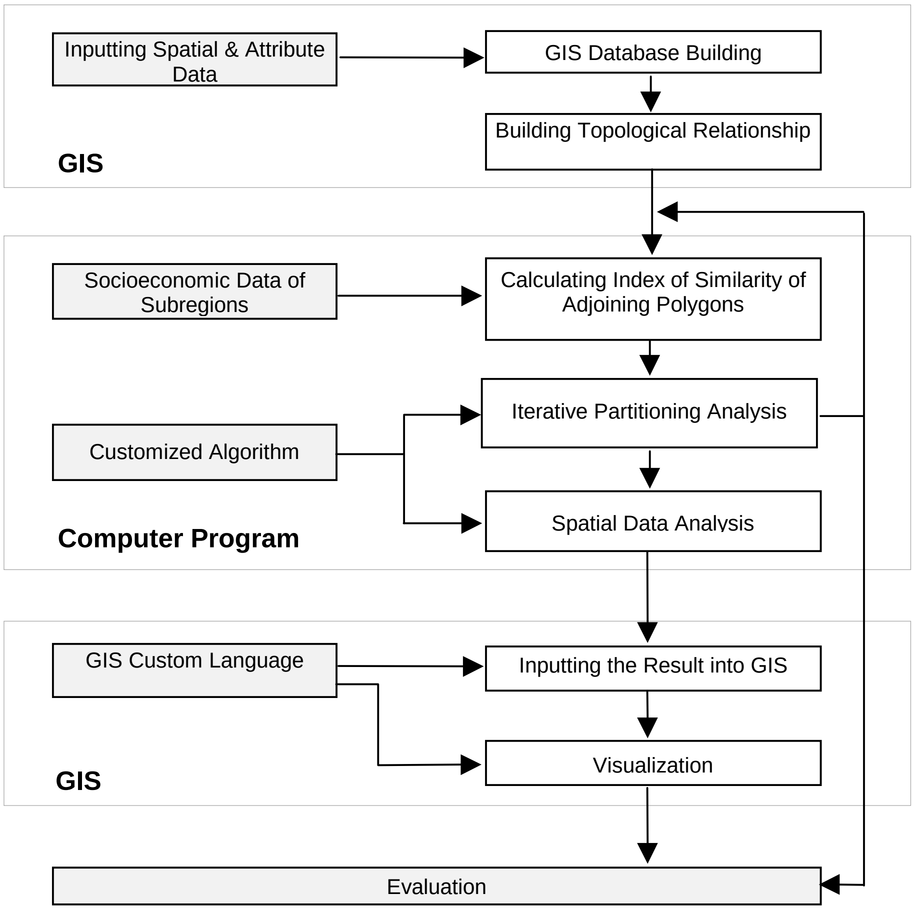

Figure 3. A Schematic Procedure of Zonal Aggregation with GIS and Statistical Analysis. Modified from Choi and Kim (1995b)

❑ *Step 2: Population Forecasting*

Population forecasting models are relatively simple compared to other sub-models in this land-use transportation modeling framework. However, the forecasted size of future population has a strong influence on the level of service which is estimated by the trip assignment sub-model at the end of each iteration. Since most population projection models have large numeric errors in formulation, the forecasted results should be carefully consulted. In this study, the linear extrapolation method and the geometric extrapolation method (Plane and Rogerson, 1994) were used.

❑ *Step 3: Land Use Activity Forecasting*

Land use activities are forecasted based on Lowry-type gravity models. In addition, the calculation of uncongested link costs for the present time (t_0) initiates this stage. The GIS network and dynamic segmentation function can assist the calculation for the link costs.

❑ *Step 4: Trip Distribution, Mode Choice, and Trip Assignment*

The proposed system follows the conventional trip distribution, mode choice, and trip assignment models, which can be seen in many UTPS-type transportation planning packages such as TRANPLAN and EMME/2.

❑ *Step 5: Visualization/Evaluation with GIS*

In order to visualize a variety of outputs from the operations of the proposed models, a GIS system is very helpful. Since the outputs of transportation models are not valid formats for GIS tools, output conversion programs should be integrated. In addition, query tools are necessary to evaluate the visualized results so that users can interpret output results and conduct a further spatial analysis; for instance, displaying V/C ratios and link volumes, and measuring congestion indices.

As a transportation planning tool, the integrated land use-transportation modeling system can support the complicated transportation planning procedures effectively, and thus the integrated system largely depends on how to integrate the proposed modeling framework with GIS technologies. In this study, the proposed modeling framework is implemented using transportation network and socioeconomic data for Seoul, Korea.

Implementation of LUTGIS

To implement LUTGIS successfully, a variety of GIS software packages, computer languages and GUI builders are utilized. First, ARC/INFO has been used as a primary GIS tool, and ArcView has been selected as the secondary GIS software. ArcView is used particularly for the data inventory system. ArcView is also used as a visualization tool for some of the outputs from LUTGIS since it has user-friendly drawing functions for charts and graphs. Second, to build user-friendly GUIs, initially ARC/INFO can be a good solution using its menu

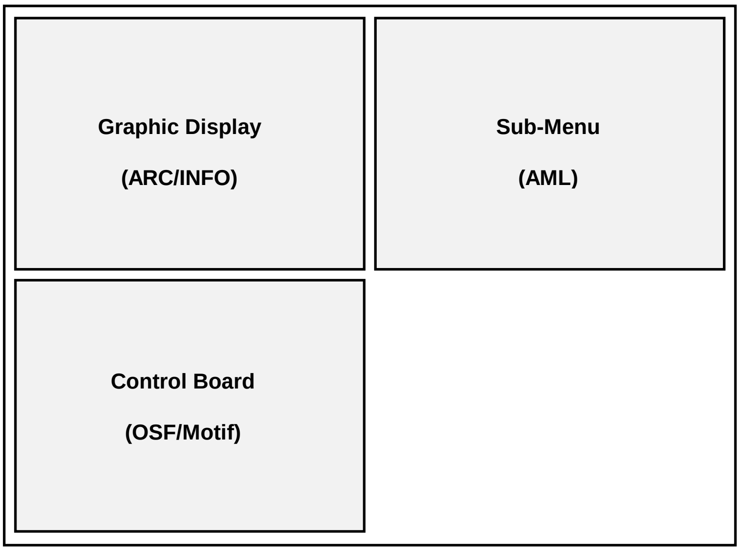

Figure 4. Proposed Working Environment for LUTGIS.

creating and editing tool -- Formedit. To create a control board, which emulates a graphical schematic chart for the proposed land use-transportation modeling system, OSF/Motif has been used. Also, a Motif-based code generator, BuilderXessory has been used as an editor for the control board. Third, both ARC Macro Language (AML) and C language support the development of the graphical control board to connect land use-transportation sub-models. All other numeric calculations take the advantage of relatively easy numeric functions in FORTRAN language. Finally, TRANPLAN has been selected for the transportation sub-models such as trip distribution and trip assignment.

Figure 4 shows a proposed working environment with the introduced tools in the LUTGIS implementation. The working environment consists of the three sub-areas on a computer screen. First, a main control window is located on the control board area. Basically, the control board indicates a sub-module, which is currently in use, and also shows the currently active database. Second, ARC/INFO generates graphic outputs of ARCEDIT and ARCPLOT on the graphic display area. Third, all Arc/Info sub-menus are displayed on the sub-menu area. Depending on the task selected from the control board, the displayed sub-menus vary. Because LUTGIS is a procedural decision making tool, the sub-menus are designed using a hierarchical structure. For instance, the primary sub-menus can create the secondary sub-menus and the tasks are governed by ARC/INFO internally. Figure 5 shows the implemented user working environment with the control board.

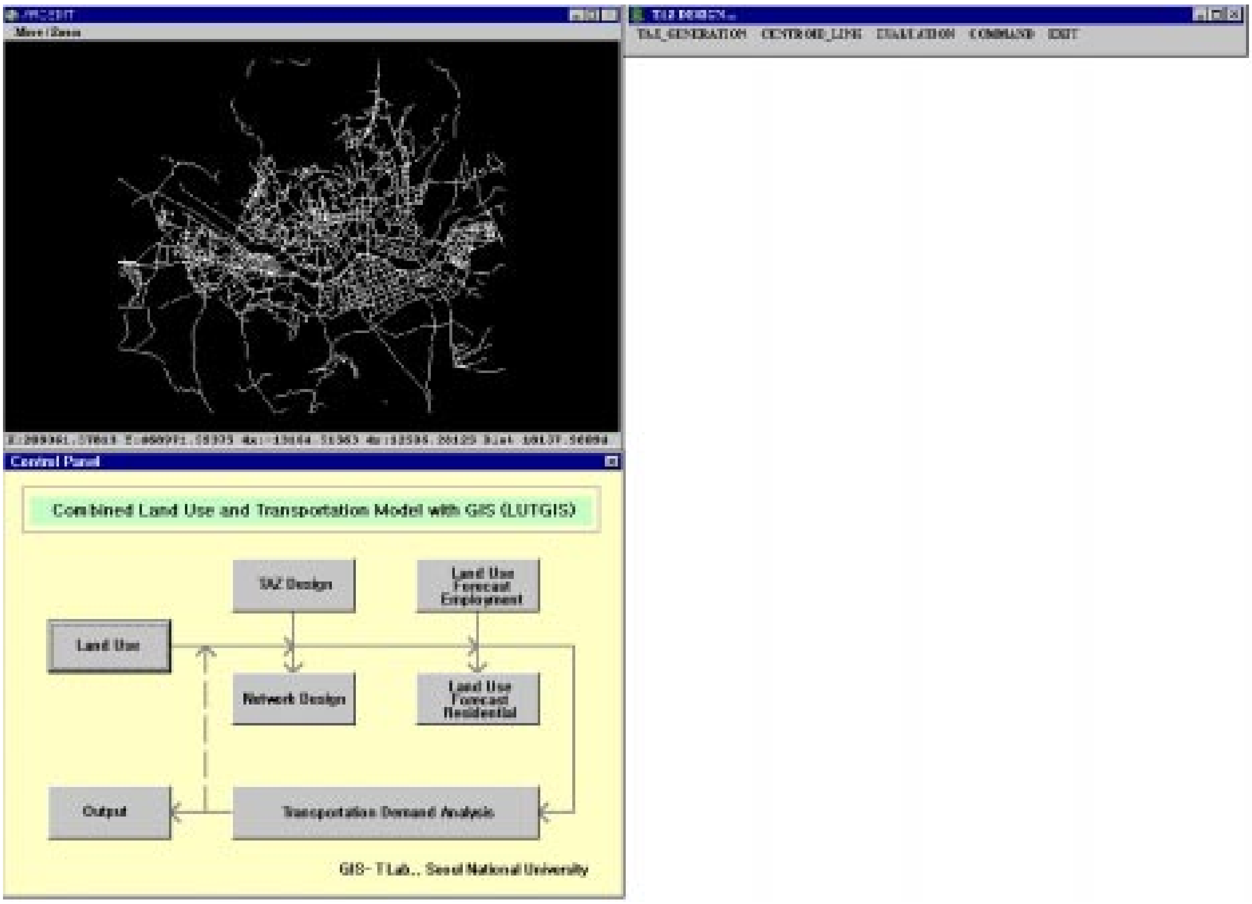

Figure 5. User Working Environment.

The Study Area

The integrated model, LUTGIS, has been applied for an analysis of City of Seoul. Data needed for this application have been collected from the three sources:

1. GIS based coverage has been obtained from unisek, Korea,
2. Socio-economic data haave been obtained from the Korea Transport Institute,
3. Other data from the Korea Statistical Information System from the Korea Bureau of statistics.

Figure 6 Shows the implemented data inventory sub-system using ArcView. In a wide window, it shows a variety of data sets including road network, land use, river system, and so forth.

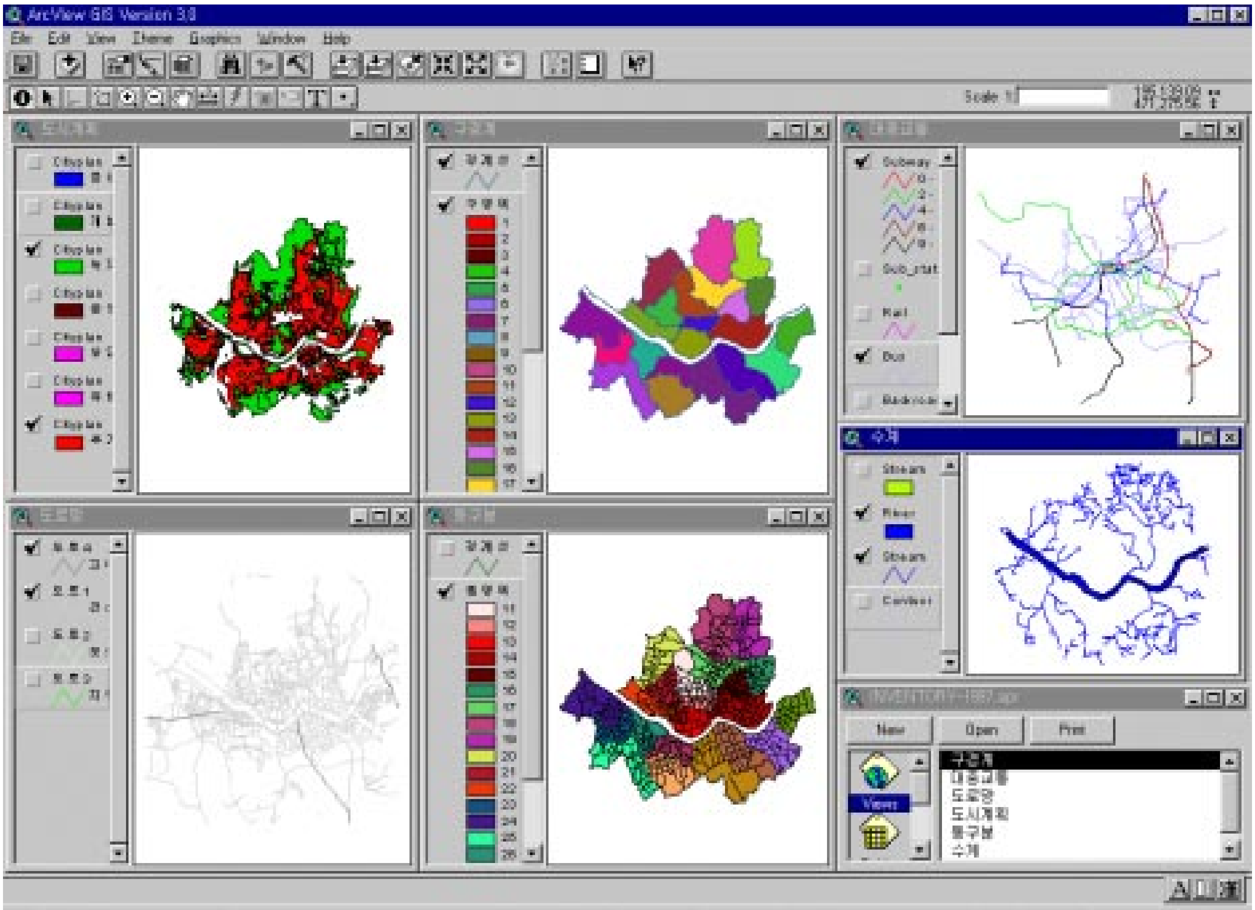

Figure 6. Data Iventory System

Visualization

After running the trip assignment model, various outputs are visualized, including the total link volumes, the V/C ratios, and trip generation and trip distribution modeling outputs. For the visualization sub-system, ARCPLOT and AML are mainly used and a customized program converts the TRANPLAN output to ARC/INFO data format. ArcView assists in displaying the trip generation output as a chart to improve users' understanding by comparisons with the trip assignment output. Figure 7 shows the trip generation chart generated by ArcView, and Figure 8 shows a trip distribution chart.

For additional spatial data analyses, various types of queries can be fulfilled; for instance, the links with very high volumes or a specific road name can be searched from the visualization sub-system. Figure 9 shows a display for the link volumes of year 2000, and Figure 10 shows a display for the V/C ratios of year 2000.

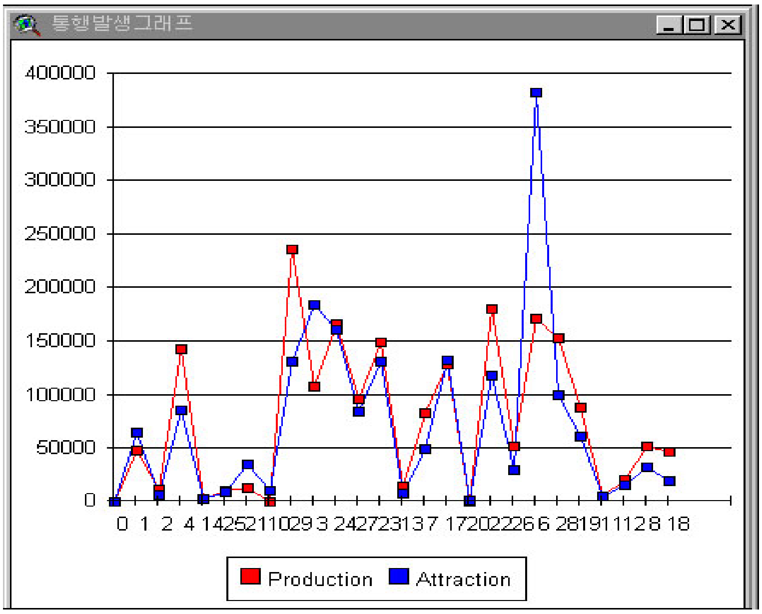

Figure 7. A Trip Generation Chart.

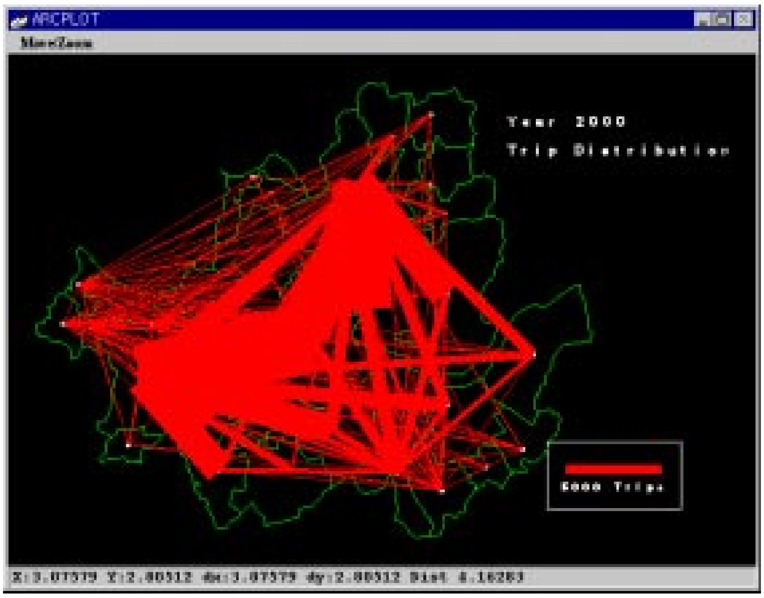

Figure 8. A Trip Distribution Graph

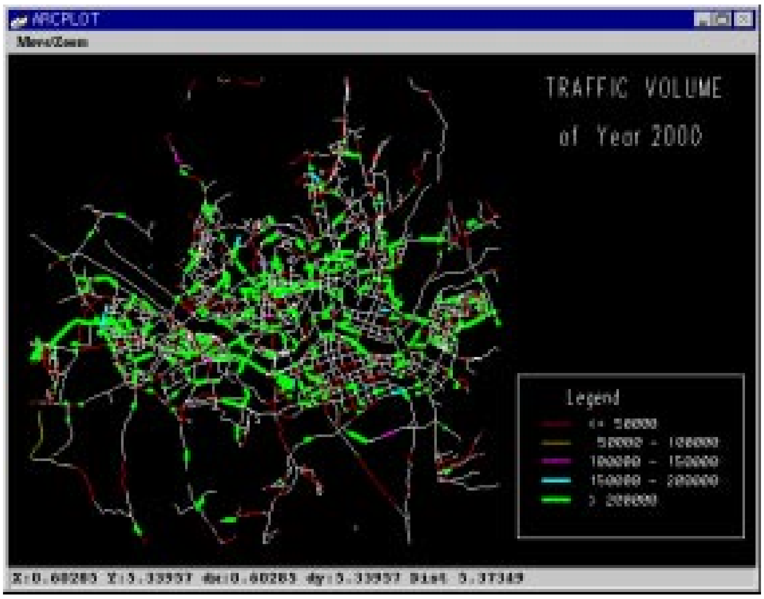

Figure 9. A Link Volume Display

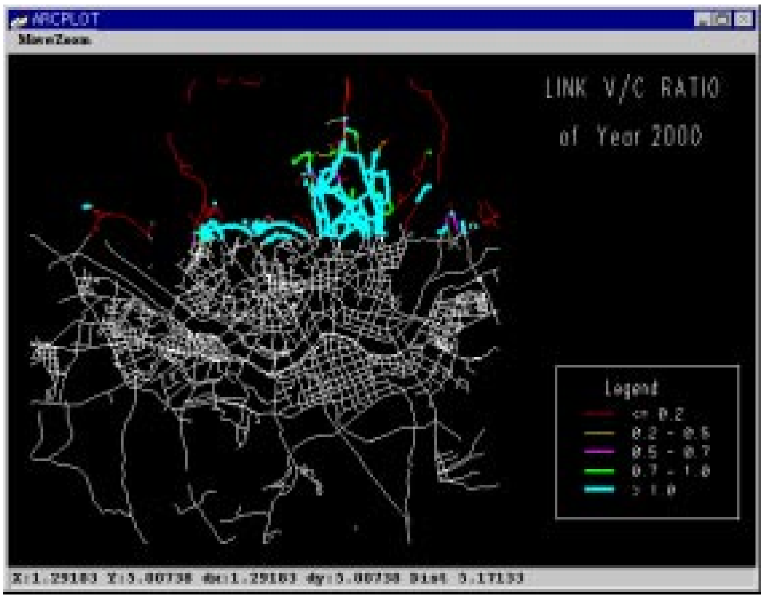

Figure 10. A V/C Ratio Display.

Conclusion

In order to develop an integrated land use-transportation modeling system with GIS, LUTGIS was proposed and implemented. During the rigorous implementation stage, several lessons were learned for future improvements.

First, land use-transportation modeling can thrive again. The recent development of advanced computing technology will make the complicated mathematical modeling feasible, and the massive data-infrastructure will provide good opportunities of data acquisition for urban modelers.

Second, GIS technologies can directly support the land use-transportation modeling by alleviating the labor-intensive data preparation stage -- data acquisition and management. Maintaining topology is another advantageous feature of GIS. By using the topological data structure, it was possible to implement the iterative partitioning technique for the TAZ generation sub-system. One of the generic GIS functions, visualization function, is still valuable for many purposes. Eventually, GISs will be not only a database management tool, but also could be the base of the system integration, including required land use-transportation modeling functions.

Third, a spatial data analysis using spatial autocorrelation coefficients is very useful to explain the reliability of generated TAZs. Since urban systems themselves are located in space, having such an analytical tool is helpful to analyze the characteristics of the urban systems.

Fourth, computer programming techniques are important for the LUTGIS implementation because commercially available GIS software packages do not provide all necessary functions for the system integration. Therefore, investing more efforts on mastering computing technologies will eventually help the system integration.

Finally, there are several remaining tasks. The entire system assumes people behave depending on travel costs in urban transportation system. However, such assumption is too general to simulate the complicated urban systems. Therefore, more research should be conducted to discover other variables that influence urban travelers' behavior. Also, land use forecasting functions should be further investigated for a more reliable, iterative system. In addition, a combined integrated transportation model needs to be developed to avoid time lags among sub-models. LUTGIS uses too many sub-models to be systematically calibrated; therefore, having a combined and integrated modeling framework could be more desirable. Another remaining task might be adopting a dynamic modeling framework rather than using a quasi-dynamic framework to simulate the dynamic nature of urban systems.

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