韓國地形空間情報學會論文集 第1卷 第1號 1993年 6月 pp. 127-140.

전통교통계획과정에 있어서 GIS의 역할 및 기능적 통합방안에 관한 연구

The Role of Geographic Information System and Its Functional Intergration Strategy in the Conventional Transportation Planning Process

崔 岐 柱*
CHOI Kee-Choo

要 旨

전통적인 교통계획 모형의 취약점으로서는 모형자체가 가지는 이론적 한계외에 이용자의 불편성(User-Unfriendness) 및 노동집약도(Labor-Intensiveness)를 들 수 있다. 본고의 핵심은 현재 정보 및 컴퓨터 분야에서 각광을 받고있는 지리정보체계(GIS)를 이용하여 기존 교통계획 모형이 가지는 몇가지의 단점을 극복함과 동시에 모형사용의 효율화를 증진해 보자는 데 있다.

GIS의 교통계획에의 응용은 크게 두가지로 대별되어질 수 있는 바, 첫번째는 GIS 자료구조의 변형을 통한 응용이고 두번째는 GIS가 지니는 그래픽 기능의 직접적 사용이다. 교통계획 및 공학의 직접적인 대상인 교통망은 교통연구의 시발이 되는 기본 자료로서 수정 및 조정이 필수불가결 한데도 기존의 계획모형에서는 교통망의 준비부터 그 수정까지는 많은 시간과 노력이 소모되었고 그에 따른 계획전반의 경직성이 나타난 것이 사실이다.

본고에서는 벡터방식의 GIS 자료가 가지는 특성의 하나인 위상관계로부터 교통망 자료를 도출하는 알고리즘이 FORTRAN을 기본으로 하여 개발되었고 이는 교통망의 수정 및 조정을 용이하게 할 뿐만 아니라 보다 정확한 교통망상의 교통량을 산출하기 위해 교통존과 교통망간의 적합성(Zone-Network Compatibility)을 검증하는데도 매우 편리한 도구가 된다. 또한 GIS 자료구조중 하나의 특성인 인접성(Adjacency) 정보는 지역적으로 동일한 특성을 갖는 지역의 통계적 분석을 통한 추출과 함께 교통존(Traffic Analysis Zone:TAZ)의 공간적 재구성을 통한 모형의 적합도를 검증할 수 있는 좋은 도구가 될 수 있다고 볼 수 있다. 또한, 이미 기존의 교통계획 모형 중 그래픽을 제공하는 것들이 있지만 그래픽은 GIS 자체가 가지는 고유한 기능중 하나인 만큼 교통계획 패키지가 제공하는 것보다 더욱 생생한 교통망 묘사(Network descrition)를 통해 교통분석후의 제반 교통특성(교통량, 교통량/용량 比, 속도 등)을 교통망상에 표시할 수 있음으로서 의사결정에 보다 많은 도움을 줄 수 있을 것이다.

ABSTRACT

The purpose of this paper is to examine the possible benefits of combining transportation planning models with geographic information systems (GIS) in the hope that intergrating these systems can alleviate the inherent problems of transportation planning models such as user unfriendliness, labor intensiveness, and theoretical limitations. Specially, this paper focuses on the issue of incompatiblity between GIS and the conventional transportation planning models in dealing with network topologies. Resolving this conflict in topologies is a conerstone for eliminating the user-unfriendliness and labor-intensiveness issues. This paper presents the developement of an algolithm that converts GIS topology into transportation network topology. The FORTRAN-based topology conversion algorithm generates transportation networks from the GIS cartographic file and establishes a communication channel between the two systems.

* 서울시정개발연구원 도시교통연구부 책임연구원

1. Introduction

Transportation planning is the process of informing decision-making processes in transportation and planning organizations. It is concerned with a variety of decision types such as short-term, long-term, capital investment, and operations management in both private aud public sectors.

Demand forecasting is an essential element in the transportation planning process. A zone-based and sequential approach to demand forecasting assumes that travelers choose a destination, a model, and a route. Therefore, in estimating travel demand, four stages of demand analysis-trip generation, trip distribution, mode choice, and trip assignment have been assumed to represent travel makers' choice behaviors.

Although it is true that different sequences can be postulated for the trip-making process, the above sequence is common in practice and has been implemented in the widely distributed computer-aided transportation planning system referred to as the Urban Transportation Planning System(UTPS) (Ben-Akiva and Lerman, 1987).

While the UTPS-type modeling package has been used to help make transportation investment or planning decisions in most planning agencies throughout the world, it has many theoretical and practical limitations. Theoretical limitations are well described in Stopher and Meyburg (1975) and Kim (1989 and 1990). Practical limitations of the UTPS-type transportation planning models can be summarized as the following:

No Feedback Issue

Due to the forward-seeking direction of the process, the entire decision to make a trip is only split into four sequential decisions and the whole process ends with the loading of the estimated volume in the network. However, in pracactice, there is some provision made for a recycling of this process. In other words, it is possible to reiterate trip distribution, mode choice and trip assignment processes by using link travel times which are the output by trip assignment as a fresh input of distribution and mode choice, and then to reassign the adjusted modal volume to reach a new equilibrium.

In addition, the sequential process of defining each zone as a node prior to the trip generation stage can be affected by even slight changes in zone boundaries. These changes in zone boundaries can produce different results in distribution, mode choice, and assignment. An iterative process that combines delineating zonal boundaries, network building and travel forecasting is needed to solve some of the problems associated with the sequential process.

User-Unfriendliness

The input generation of transportation demand modeling requires the modeler to be familiar with the modeling package being used. It is very time consuming to master an entire manual, such as for TRANPLAN, in order to use the package correctly and effectively.

Also interpretation of the model output generally involves printing the whole or Partial output, or retrieving voluminous output into a text editor to review the numerical results[*1].

*1)Recently, graphic support routines have been added to the existing UTPS-type transportation demand modeling packages such as MINUTP and TRANPLAN. In the MINUTP, NETVUE exist as components for viewing and editing transportation networks. NIS(Network Information System) exists as a separate graphic display and editing system for TRANPLAN. However, most probably EMME/2 can be considered as the first interactive graphic-based turnkey system for modeling the transportation planning process.

Labor-Intensiveness

The following key steps in the modeling process are very time-consuming and burdensome:

- transportation network generation (network coding and node-link data preparation)
- socio-economic data preparation based on delineated traffic analysis zone (TAZ).

Transportation planners have to prepare maps to describe study areas and actual transportation networks. As O'Neill (1991) states, network generation requires extensive data collection and integration efforts. Furthermore, generated networks are frequently modified to reflect changes such as:

1. changes in study area boundaries
2. changes in zone delineation due to the land use change
3. modified networks (link shape and node location change) for testing alternative network scenarios
4. link attribute(e.g., capacity and speed limit) changes.

Data acquisition is expensive. Even when sufficient and relevant data are already available the cost of converting data into a usable form can be substantial. Each of these factors contribute to the labor-intensive character of this process.

With those problems of the conventional transportation planning in mind, the purposes of this paper are two-fold:

1. To study the nature and issues of the application of geographic information systems to the transportation planning process in order to make the process less labor-intensive more user-friendly and more interactive.
2. To develop an algorithm that can build transportation networks directly from GIS topology.

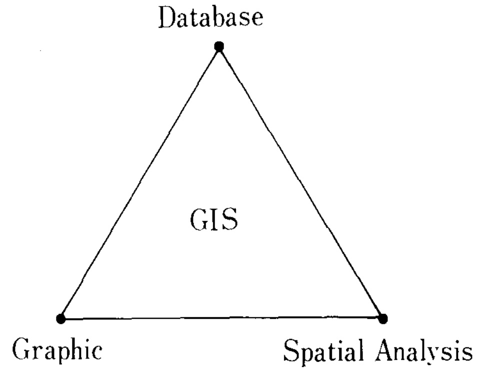


Figure 1: Three Distinct Aspects of GIS (Antenucci, 1991)

A major contribution of this paper is to provide a basic framework for providing the capabilities to develop a transportation network structure, where GIS is integrated not only to solve the problems of the conventional transportation planning models but to effectively support decision-making activities in transportation planning.

2. GIS as a Transportation Planning Tool

GIS is a computer-assisted and integrated environment for geographic data creation, storage, retrieval, management, manipulation, analysis, and display (Lai, 1990). It relies on the integration of three distinct aspects of computer technology: data base management, routines for displaying and plotting graphic representation of the data, and algorithms and techniques that facilitate spatial analysis as shown in Figure I (Antenucci et al., 1991).

GISs are comprised of some quite sophisticated computer software, but they all contain the following major components (Marble, 1987):

Data input subsystem - collects and/or processes spatial data derived from existing maps, remote sensors, etc.

Data storage and retrieval subsystem - organizes the spatial data in a form which permits it to be quickly retrieved by the user for subsequent and accurate updates and corrections to be made to the spatial database.

Data manipulation and analysis subsystem - performs a variety of tasks such as changing the form of the data through user-defined aggregation rules or producing estimates of parameters and constraints for various space-time optimization or simulation models.

Data report subsystem - displays all or part of the original database as well as the manipulated data and the output from spatial models in tabular or digital cartographic map form.

Spatial geographic data are those which represent spatial objects in three forms : points, lines, and polygons or areas. In GIS, all these different data-types are represented in digital rather than analog form. Therefore, to use computers for handling spatial data, we must reduce our data to the computer's level of comprehension. According to Parker (1988), we have to specify three things for the computer:

location - Where each feature is in geographic space (spatial information)
attribute - What each geographical feature is (descriptive information)
topology - What kind of spatial relationship each geographical feature has to other geographical features

The spatial information describes the location and shape of geographic features and their relationships. The descriptive information represents attributes of particular geographic features.

Since most transportation planning activities involve spatial data, the significance of GIS in transportation planning lies in its ability to combine spatial data manipulation with graphics and mapping.

2. 1 Geographic Information Systems for Transportation : "GIS-T"

The adaptation and adoption of GIS for transportation purposes is called GIS-T (Lewis, 1990). It is an environment or framework for managing and analyzing spatial data related to transportation, especially the following tasks (Lewis and Fletcher, 1992):

- managing and manipulating networks
- updating and displaying network attributes
- spatial analyses
- routing analyses
- georeferencing
- linking to other applications

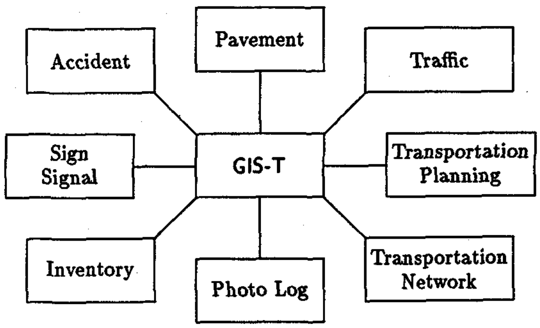


Figure 2: Application Areas of GIS-T
(Fletcher and Lewis, 1989)

So far, examples of GIS-T databases include pavement management, accident management, traffic management, inventory, sign and signal maintenance, photo logging, and transportation networks, as shown in Figure 2(Examples of applications in each area can be found in AASHTO, 1989-92). Since transportation data basically deals with linear transportation networks, GIS-T puts more emphasis on networks which are linear-based arc systems rather than area-based polygons.

However, existing GIS packages are not equipped to deal with the linear, rather than polygon, data that most transportation agencies require (Lewis and Fletcher, 1992). Therefore, it was difficult to facilitate the more efficient data storage of multiple representations of a road network.

2. 2 Problems of Existing GISs for GIS-T

Many transportation professionals feel that GIS-T has the following advantages over the conventional database approach for transportation (Eberlein,1992):

Increased productivity - Visualized data is faster and easier to comprehend, and can be delivered at a much higher information density.

Improved work quality - Direct interaction with objects helps to uncover hidden problems, to demonstrate causality intuitively and to yield new insights.

Superior data integration - All data can now be integrated using their locational attributes.

However, it is difficult to address many transportation problems shown in Figure 2 using commercially available GISs. Eberlein (1992) further pointed out that the existing GISs have the following problems:

Entity recognition problem - Entities commonly dealt with by transportation professionals are not lines and points but roads and routes. Existing GISs define only simple visual entities such as points, lines, and polygons; they do not recognize more complex, but common, transportation entities such as roads and routes. For example, although a road or a route can be displayed as a set of lines, the user should specify all the relevant lines making up the road and the route. This makes some GIS operations, like queries, complex and data management more difficult. Futhermore, the road attribute have to be associated with the lines and not the road itself. That is, queries must be expressed at the line level instead of the road level.

Topology construction problem - Most existing GISs try to derive topological relationships from the geometric properties of the entities. For example, GISs normally generate a node at any point where lines cross, ignoring the fact that cross on a two-dimensional plane does not necessarily mean intersect in the three dimensional world.

Data connectivity problem - The separation of spatial and a spatial data artificially impose obstacles for data integration by breaking the naturally existing connections between the two data sets causing anomalies for data manipulation. Furthermore, there is no mechanism for preserving the topologies between multiple GIS layers, each of which contains different entities.

Reference system problem - While most GISs use a single reference system (Cartesian coordinate system), transportation data employs multiple reference methods such as mile-posts, log-miles, and the arbitrary reference system. A fully functional GIS-T should support a conversion from one to another reference system.

Representation level problem - Different transportation users require different information. For example, an intersection may be either a point type or an area type, depending on who is doing what. Current GISs only provide a single level of representation for the same entity.

Non-Polygon operation problems - Most spatial operations are provided only for polygons, few for lines and points. As shown in Table 1, it is not possible to overlay lines with points, lines with lines or points with points, which are more important overlay operations for transportation modeling.

2. 3 GIS-T Applications

The recent development of dynamic segmentation within the GIS framework is a method of referencing road attribute data of a variable for the segmentation of the road network.

Table 1 : Relationships Between Spatial Features and Possible Overlays (Adapted from Lewis and Fletcher, 1992 and Gatrell, 1991)

class	Points	Lines	Areas
Points	- is a neighbor of - is allocated to (no)*	- is near to - lies on (no)*	- is a centroid of - is within (yes)
Lines	(no)*	- crosses - joins (no)**	- intersects - is a boundary of (yes)
Ares	(yes)***	(yes)***	- is overlain by - is adjacent to (no)

* : Spatial Equivalence Issues
** : Network Conflation Issues
*** : Inverse Issues

It allows users to store multiple overlapping attributes in the database without duplicating route geometry, resulting in a sizable data storage gain and the efficiently manipulation of transportation entities (such as routes-a combination of arcs, section-aportion of arc, and event-node). It can resolve some of the problems identified by Eberlein 1992) such as the entity recognition problem and the reference system problem.

In spite of the problems of currently available GISs, several applications have been developed for an effective and efficient transportation data management(AASHTO, 1989-92). More broad views of GIS-T application to frameworks in planning and engineering can be found in Lewis and Petzold(1990). Those applications are as follows:

Highway

- planning of urban and regional roads
- inventory of roads(bridges, signals, lights, sign, etc.)
- pavement management system
- bridge maintenance application
- highway planning
- traffic engineering
  1. accident analysis
  2. highway safety program development
  3. customized traffic ordinance management
  4. state-wide traffic signal system management
  5. traffic requests and investigation
  6. policy and standards development
  7. special traffic engineering system studies
  8. traffic demand forecasting
- corridor selection
- winter storm management
- environmental impact of transportation facilities

Public Works

- facility mapping and management (manholes or sewers, etc)
- solid waste planning
  1. landfill planning and management
  2. collection route planning and management
  3. meter reading route planning and management

Transit and School Bus

- ridership corridor analysis
- route planning
- school redistricting
- school bus routing and scheduling

Others

- airport noise abatement, facility mapping and management
- medical and policy emergency responses
- hazardous material routing
- rail management
- port management
- disaster management.

All of the applications identified above are descriptive and static tasks. GIS applications to more dynamic transportation analyses are beginning to appear. Lee presented a simple model of dynamic vehicle routing with an emphasis on its system configuration and data organization (Lee, 1990), while Insignares and Terry (1991) applied GIS to traffic control. Research is underway to investigate the role of GIS in resolving the temporal data problem associated with the ATMS requirement to predict traffic flow (AIThah and Barrera, 1990). In the area of the intelligent vehicle and highway systems (IVHS), a GIS based ATMS serves as an ideal model since many of the core functions required for an IVHS will be available through a GIS based ATMS. The spatially referenced structure of the GIS provides a data foundation for the real-time analysis of IVHS remote monitoring and control device, including in car navigation equipment (Wheatley, 1992).

3. The Role of GIS in Transportation Planning Process

Transportation planning involves a great deal of information on features that are geographically distributed over a study area. It utilizes socio-economic data such as population and employment statistics collected for spatially homogeneous areas to estimate trip production and attraction(Simkowitz,1989).

Data collected for network development is a spatial component comprised of a set of nodes and links. Based on the similarity of spatial data used in transportation system modeling and geographic information systems, a GIS could be used to manage data and information needed for transportation network development. In addition, a GIS allows many elements of the spatially distributed transportation database to be linked to the graphical display.

Some GIS functions can be incorporated into the modeling process of transportation planning to solve the problems inherited from the UTPS-type transportation planning models. These functions are:

1. a database integrating function providing appropriate data in the zone delineation and trip generation stages, and a display device for presenting non-spatial data in graphics form
2. a network topology-generating function to provide the basic node-link scheme and necessary attribute data
3. a network calibrating function that can produce most suitable network for trip distribution, mode choice, and traffic assignment
4. a function assisting traffic zone delineation scheme both through the spatial analysis and the use of topological information
5. a function displaying outputs of transportation planning models such as traffic volume, v / c ratios, travel time, etc.
6. a spatial analyst function to perform spatial search and query (such as the routing and allocation of transportation supply centers)

A GIS, as a database integrator and display device, can address the issues of aggregation and user-unfriendliness associated with conventional transportation planning models. As an input data generator, a GIS may overcome the aggregate nature of the transportation planning model structure that ignores spatial variations. Specifically, a GIS can manage and manipulate spatially oriented data structures, such as parcel-based data in a study area. In addition, a GIS as an output interpreter can summarize large amount of numerical data into single pictures that "tell a thousand words" (Replogle, 1989).

The role of GISs as network topology generators may reduce the number of labor-intensive tasks in transportation network data construction. The arc-node topology of a digital map in vector GISs can be a basis for transportation node-link data construction.

The first role of GISs in the transportation planning process is natural since the database function of GIS is a key element of GISs. The second role of GISs is available in vector-type GISs and the conversion of GIS topology can be accomplished if GISs are coupled with procedural programming language routines, such as the FORTRAN routines described in this paper.

The third role of GISs is especially crucial for transportation planners. When working with transportation networks, transportation planners add or delete a set of transportation network segments not only to adjust the link volumes, but to study the feasibility of a certain road which is composed of a set of link segments. With conventional modelng, it is very time consuming to revise all related link data. However, with the help of the GIS spatial query, network segments can be selected that constitute a new coverage, and from that coverage, a new to topology can be generated by the second function. The generated topology is an input for a topology conversion program which will convert the arc-node topology into the compatible link-node topology of the transportation planning model.

The fourth role of GISs is very important because it can partially eliminate the problem of the sequential approach of the conventional transportation planning models in a sense that a new scheme of the traffic analysis zone can affect the whole four-step transportation planning process. In a transportation study, the traffic zone aggregation problem involves spatial clustering, meeting the following general requirements proposed by Garber and Hoel(1988)[*2)]. The spatial analysis function of GISs can assist in identifying the zone scheme along with other statistical procedures such as cluster analysis. At the same time, the topology representing the contiguity of polygons can help identify the contiguous spatial basic units to be agglomerated homogeneously.

The last two GIS roles are uses of the generic features of GISs. A GIS provide more true to life graphics than any other graphics system. The results of transportation planning models can be added to the database of GIS and the updated

---

*2)They proposed a set of criteria for delineating the traffic analysis zone. They are :

1. Socio-economic characteristics should be homogeneous.
2. Intrazonal trips should be minimized.
3. Physical, historical, and political boundaries should be utilized where possible.
4. Zones should not be created within other zones (i.e., no "doughnuts").
5. The zone system should generate and attract approximately equal trips and/or contain approximately equal population, households, or area per zone.
6. Zones should be defined by census tract boundaries where possible.

database can be displayed, analyzed, and manipulated by further utilizing the analysis functions of GIS.

4. Integrating GIS into Transportation Planning Models : Issues

In establishing the supportive role of GIS in transportation planning process, it is very important to overcome the inherent topological network differences between the two systems, especially differences between the GIS and transportation network topology. Solving the gap between the two systems can eliminate the problems of the conventional transportation planning models identified earlier.

Table 2: Handling of Network Data in GIS and Transportation Model

Transportation Model	GIS
Single purpose	Multi-purpose
Model-driven	Data-driven
Abstract context	Geographic context
Single topology	Many topologies
(link-node)	(point, arc, polygon, network)
Link-node structures	Chain structures
Sort-indexed	Spatially-indexed

(Lewis and Fletcher, 1992)

Table 4 shows the fundamental differences between transportation planning models and GISs in the handling of network data. Gaps between the two are expected since each system was developed for its own specific purpose by way of different approaches. While the transportation planning model uses a mathematical approach, GIS uses a,more visually-oriented approach.

4. 1 Topoloical Gap BetWeen GIS and Transportation Planning Models : General Network Discrepancy

Patterson (1990) recognizes the linkage gap between GIS and transportation planning models and provides three situations (shown in Figure 3), in which one-to-one correspondence in networks between the two systems is not always possible. In other words, it is difficult to identify the links in the transportation networks that correspond to particular links in the GIS networks.

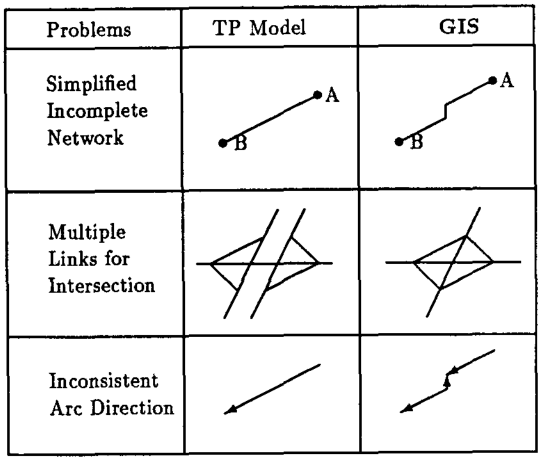


Figure 3 : Network Discrepancies Between TP Model and GIS(Patterson, 1990)

As shown in Figure 3, transportation networks are usually simplified versions of the real street network encompassing only interstates, arterials and major collectors. This results in one-to-many correspondence with a more comprehensive GIS network. The second problem he identified is that some transportation models treat intersections and divided highways as a pair of one-way links, whereas many GIS street networks (including TIGER and DIME*3) do not. This results in a

*3)Stands for Topologically Integrated Geographic Encoding and Referencing and Dual Independent Map Encoding.

many-to-one correspondence between the two networks. The last problem is the inconsistency between the two networks. Several links in GIS will not have consistent directions with respect to each other, although taken together they correspond to a single link in the transportation network. These problems are common if a planner is working in the United States because standard digital map data are becoming more and more important in the application. If the planner is not in the U.S., these problems are not always present.

There is another problem associated with GIS and transportation planning model linkage, in addition to those pointed out by Patterson (1990). Even after those problems have been solved, the distinction of 'zone node'(where trips originate and end) and 'intersection node'(where two or more links meet together) should be made in order for GIS networks to be effectively used as transportation networks, to provide network data to transportation planning models. Therefore, this distinction gives rise to a question of how to directly use the topology of vector GIS in the transportation network, and how to construct a communication channel between the two so that the output of a transportation planning model can be fed to a GIS to display it.

Arc-node topology created by most of the commercially available GISs cannot be directly used as a node-link scheme in the UTPS-type network since there is no way to assign node attributes to nodes.*4) The main reasons why arc-node topology is directly incompatible with the node-link scheme are:

- Typical transportation planning models require each zonal node to be numbered from 1 to n (if there are n TAZ's)*5), whereas the intersection nodes can be numbered without such restrictions.

- There is no distinction between zonal node and intersection node in the GIS topology. In addition, it is difficult to change the arc-node topology in such a way that zone nodes should be numbered from 1 to n.

It may be proposed that the arc-node topology can be modified to coordinate with the transportation planning model. However, the nodes generated during the digitization process are not easy to change using commands available in GIS modules. Furthermore, it is useless to couple GIS and transportation planning models if every network change in GIS should require the manual change of the arc-node topology. Since this is the case, a topology conversion algorithm should be developed not only to accommodate the topological difference between GIS and transportation model but also to automate the conversion of the GIS arc-node topology into the transportation planning model's node-link topology on a real-time basis.

5. Integrating GIS with Transportation Planning Models: Transportation Network Building from GIS Topology

---

*4)Recently the NAT-node attribute table has been introduced to the ARC/INFO version 6.1. This enhancement will alleviate many issues in using a GIS layer for preparing the transportation network.

*5)Most of the UTPS-type transportation planning packages, such as TRANPLAN, EMME/2, MINUTP, (Micro) TRIPS and TMODEL2, employ this zone numbering structure. That is all zonal nodes must be consecutively numbered beginning at 1 to the number of zonal nodes with no gap in between, while all remaining non-zonal nodes (intersection nodes) can be numbered in any order.

The main thrust of the topology conversion is to provide the capability to develop a transportation network structure and attach attribute data to this structure, such that the requirements of the chosen transportation planning model is satisfied. Recent efforts for this kind of research have focused on reconciling existing digital transportation networks with existing digital cartographic databases (Patterson, 1990). However, numerous problems caused by the nature of transportation networks of the conventional transportation planning model and digital encoding practices of topographic databases limit the success of this approach (O'Neil, 1991).

5. 1 A Topology Conversion : From GIS to Transportation Networks

The topology conversion algorithm proposed in this research first selects the zone nodes from all nodes in the coverage created in the digitization process, based on special values assigned to User-ID for each 'zonal arc' which correspond to links that connect zone centroids and nodes. Then it renumbers each zone node and intersection nodes.

As shown in Figure 4, whatever node is connected to a zone centroid(assumed to be chosen before the digitization process and 1 and 2 in Figure 5(d), and 3 and 2 in (c), respectively) will be selected in Phase I based on the arc User-ID set bigger than θ (that is, the A and E value in Figure 5(c) should be bigger than θ), during the digitization process to differentiate a plain arc from a zonal arc (a zonal arc may be defined in such a way that the User-ID value of the arc exceeds θ [*6)]. Intersection nodes are updated using the formulas in the box.

The selected nodes in Phase I will be sorted and renumbered from 1 to n in phase II to create a compatible form for transportation planning models. The converted and rewritten arc-node topology will be the basic input for the transportation planning model's network generation module, and it can be combined with attribute data such as the capacity and speed of links based on the User-ID value of each arc.

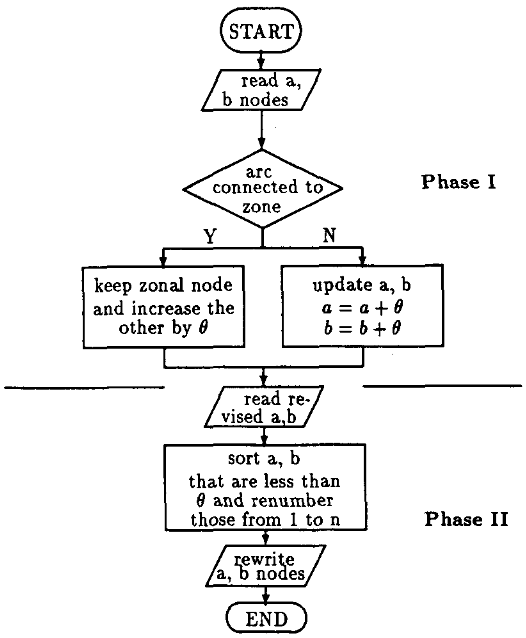


Figure 4. General Flow of the Topology Conversion Algorithm

5. 2 An Example

According to ITE (Institute of Transportation Engineers) Technical Council Committee 6F-41 (1991), UTPS is still widely used by 22 DOTs in forecasting future traffic. MINUTP and QRS II were each used by 9 states, TRANPLAN by 5

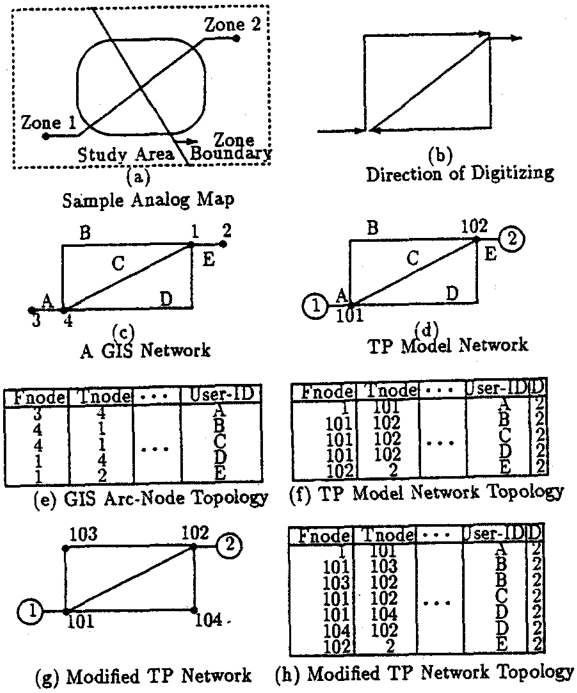
*6)In the case study, θ value of 3000 has been used, since the DOS (Disk Operating System) version of TRAN-PLAN can handle up to 3000 zones.

states, TMODFL by 4 states, and MicroTRIPS and EMME /2 by 3 states. In this example, TRANPLAN was used for integration with pc ARC /INFO GIS.

Figure 5 shows the difference between the topologies and a progress of the adoption of GIS topology to transportation network topology. Let's assume that there is a study area that consists of two zones as shown in (a) of Figure 5. The digitizing process in (b) will represent the topology in graphical form (c), and in abstract form (e). However, transportation network topology (network data structure) is different from the GIS topology in that the zone centroid is numbered from 1 to 2 as shown in (d) and (f). If there are n zones, numbers from 1 to n will be reserved as zone nodes. The network coding scheme in (d) assumes that the total number of zones is less than 100 (θ =100) and that every intersection node is coded greater than 100. Figures in (g) and (h) represent the modified transportation network and the topology that must be differentiated from the topology in (d), because multiple links between a pair of nodes are not allowed in the UTPS-type transportation planning packages. In other words, a specific link should be composed of a unique pair of nodes. In summary, what the topology conversion algorithm does is to convert the GIS arc-node topology in (e) to the transportation planning model's network topology in (f) without changing arc attributes. Once the B and D arcs in (c) are split into four different arcs in (g), the topology conversion algorithm will produce the transportation network file in (h) that can be directly used by transportation planning models.

6. Conclusion and Future Research

In linking GIS and the transportation planning model, GIS has been adopted as a database integrator, a display device for transportation planning model output, and a network topology generator for providing the transportation planning model's network topology via a topology conversion algorithm.



(e) GIS Arc-Node Topology

Fnode	Tnode	···	User-ID
3	4		A
4	1		B
4	1	···	C
1	4		D
1	2		E

(f) TP Model Network Topology

Fnode	Tnode	···	User-ID	D
1	101		A	2
101	102		B	2
101	102	···	C	2
101	102		D	2
102	2		E	2

(h) Modified TP Network Topology

Fnode	Tnode	···	User-ID	D
1	101		A	2
101	103		B	2
103	102		B	2
101	102	···	C	2
101	104		D	2
104	102		D	2
102	2		E	2

Figure 5 The Topological Difference between GISs and Transportation Planning Models (column D in (f) and (h) represents whether the link is either one-way or two-way direction with the same attribute data.)

This linkage between GIS and transportation planning models can not only enhance the user-friendliness of the transportation planning model in a sense that an automatic generation of the transportation networks is guaranteed, but it can also partially eliminate the labor-intensive and no-feedback problems. It will also save a lot of time by automating the conversion process of the GIS topology to transportation network topology, even with changes to the network.

To further enhance the synergetic effects of integration, an expert system can be added to the current GIS and transportation planning model linkage to facilitate the whole process of modeling activities by providing a better user-interface and by solving many of the judgmental issues encountered. In addition, the user-interface enables the decision makers to effectively perform "What-If" type simulations by allowing them to quickly see the effects of changes, particularly in the following areas:

1. changes in traffic analysis zone scheme
2. network shape changes
3. network attribute data changes
4. different modeling sequences
5. different modeling techniques
6. different model parameters

REFERENCES

1. AASHTO. 1989. *Proceedings of the 1989 Geographic Information Systems for Transportation Symposium.* Washington, D.C.
2. AASHTO. 1990. *Proceedings of the 1990 Geographic Information Systems for Transportation Symposium.* Washington, D.C.
3. AASHTO. 1991. *Proceedings of the 1991 Geographic Information Systems for Transportation Symposium.* Washington, D.C.
4. AASHTO. 1992. *Proceedings of the 1992 Geographic Information Systems for Transportation Symposium.* Washington, D.C.
5. Al-Thah, K. and Barrera, R. 1990. Temporal Data and GIS: An Overview. *Proceedings of GIS /LIS'90: Volume 1.* Anaheim, CA.
6. Antenucci, J.C. et al. 1991. *Geographic Information Systems: A Guide to Technology.* Van Nostrand Reinhold. New York, NY.
7. Ben-Akiva, M. and Lerman, S.R. 1987. *Discrete Choice Analysis: Theory and Application to Travel Demand.* The MIT Press. Boston, MA.
8. Garber, N.J. and Hoel, L.A. 1988. *Traffic and Highway Engineering.* West Publishing Co. New York, NY.
9. Insignares, M. and Terry, D. 1991. Geographic Information System in Traffic Control. *Proceedings of the 1991 Annual Conference of the Urban and Regional Information Systems.* San Francisco, CA.
10. ITE Technical Council Committee 6F-41. 1991. Traffic Forecasting on State and Provincial Highway Segments. *ITE Journal* 61 : 25-30.
11. Kim, T.J. 1989. *Integrated Urban Systems Modeling : Theory end Applications.* Kluwer Academic Publishers. Norwell, MA.
12. Kim, T.J. 1990. *Advenced Transport end Spatial Systems Models : Application to Korea.* Springer-Verlag. New-York, NY.
13. Lai, Pohchin. 1990. Feasibility of Geographic Information Systems Approach for Natural Resource Management. *Environmental Management.* 14: 73-80.
14. Lee, J, 1990. A Data Model for Dynamic Vehicle Routing with GIS *Proceedings of GIS/LIS'90 : Volume 1.* Anaheim, CA.
15. Lewis, S. 1990. Use of Geographical Information Systems in Transportation Modeling. *ITE Journal* 60: 34-38.
16. Lewis, S. and Fletcher, D. 1992. *Data-The GIS Foundation.* Presented at the Pre-Conference Workshop on Geographic Information Systems for Transportation Symposium. Portland, OR.
17. O'Neill, W.A. 1991. Developing Optimal Transportation Analysis Zones Using GIS. *ITE Journal* 61: 33-36.
18. Parker, H.D. 1988. The Unique Qualities of a Geographic Information Systems: A Com-

mentary. *Photogrammetric Engineering and Remote Sensing* 55: 1547-1549:

19. Patterson, P.E. 1990. An Evaluation of the Capabilities and Integration of Aggregate Transportation Demand Models with GIS Technologies.
20. *Proceedings of the 1990 Annual Conference of the Urban and Regional Information Systems Association*: 330-342. Boston, MA.
21. Lewis, S. and Petxold, R. 1990. GIS and Transportation. *Pre-Conference Workshop on GIS/LIS'90.*
22. Replogle, M. 1989. Integration of a Geographic Information System with Computer Transportation Models for Land Use and Transportation Planning. *Second Conference on Application of Transportation Planning Methods.* Transportation Research Board. Orlando, FL.
23. Simkowitz, H.J. 1989. GIS in Transportation Planning and Operation. *Public Works* July :62-67
24. Wheatley, C.F. 1992. A Geographic Information System Technology Survey for Project Cornerstone. *Proceedings of the Geogrephic Information System for Transportation.* Portland, OR.