An Intergration of Transportation Planning Process with Geographic Information Systems (GIS)

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1 Introduction

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 mode, and routes. 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. Regardless of the posibility that different simulation sequences can be postulated for the trip-making behavior, the above sequence is common in practice and has been implemented in the widely distributed computer-aided transportation planning system called as the Urban Transportation Planning Systems (UTPS).

While the UTPS-type modeling package has been used in helping make transportation investment or planning decisions in most of the planning agencies throughout the world, it has many theoretical and practical limitations. Theoretical limitations are well described in Stopher and Meyburg (Stopher and Meyburg, 1975). Their critique about the UTPS-type include the following limitations.

The first problem is aggregation. In the conventional zone-based model, a centroid is assigned to each zone to represent the characteristics of the transportation study area. By modeling an area as a single node, bias is introduced in the description of the socio-economic characteristics of the area. This bias may ignore the spatial variations of key attributes within zones, such that they exceed the variance between zones, leading to a false conclusion due to overly aggregate data.

The second problem is no feedback. 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.

The third problem is user-unfriendliness. The input generation of transportation demand

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modeling requires the modeler to be familiar with the modeling package being used. It is very time-consuming to master the whole manual, such as the TRANPLAN manual, in order to use the package correctly and effectively. 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]

The final problem is labor-intensiveness. Especially, the following key steps in the modeling process are very time-consuming and burdensome. They are: transportation network generation (network coding and node-link data preparation) and 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: changes in study area boundaries, changes in zone delineation due to the land use change, modified networks (link shape and node location change) for testing alternative network scenarios, and link attribute (e.g., capacity and speed limit) changes.

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

Based on the four-step sequential trip making behaviors, this paper tries to explores how the integration of GIS technology can solve the problems listed above by combining the ARC/INFO Geographic Information Systems (GIS) and a transportation planning package called TRANPLAN. More specifically, this paper addresses the following questions:

1. How can a GIS model be linked to a transportation planning model by overcoming some problems of transportation planning models mentioned above?

2. How can an integrated system work as a decision aid tool ?

2 The Applicability of GIS to the Transportation Planning Process

Recent developments in computer software technology have helped create some useful computer-aided systems that can be used in transportation planning process. Table 1 shows the characteristics of software that have been used in solving transportation problems. Spreadsheets

[1]Recently, graphic support routines have been added to the existing UTPS-type transportation demand modeling packages. In the MINUTP, NETVUE exist as components for viewing and editing transportation networks and NIS supports the same function for TRANPLAN.

and databases have been introduced and used earlier than CAD and GIS.

Computer graphics have been an important aid in the analysis and interpretation of data and provide substantial assistance in the description, analysis and design phases of a diverse

Software Type	Function	Unit
Spreadsheet	store and manipulate numbers	number/cell
Database	structure numbers and words into records	record
CAD/CAM†	input and manipulate drawings	spatial object
GIS	structure and join drawings and records into intelligent maps	topological spatial object

Table 1: Comparison of Recent Software Developments

transportation projects (Schneider 1984). More recently, CAD and GIS have been used in areas such as pavement management, accident inventory and maintenance management. While both GIS and CAD are dealing with spatial objects graphically, GIS is different from CAD in that it has the ability to create new information (See Antenucci et al. 1991 and Lewis 1990 for more information.).

2.1 GIS and Transportation Systems Modeling

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, GIS could be used to manage data and information needed for transportation network development. In addition, GIS allows many elements of the spatially distributed transportation database to be linked to the graphical display.

However, as noted earlier, the database function of GIS has been mostly used for descriptive-type problems. Even though GIS can perform spatial analysis and network operations that are not available in CAD-type software, not all modeling activities of transportation planning process can be achieved. Therefore, it seems more reasonable to combine the transportation planning models and GIS than to try to obtain solutions only within GIS.

Table 2 shows the fundamental differences between transportation planning models and GIS in the handling of network data. Gaps between the two are expected since each system was developed for its own specific purpose. In combining the two systems, the topological gap of the data structures between the two systems should be resolved in order for a combined system to work to overcome the problems of transportation planning models mentioned before.

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 2: Handling of Network Data in GIS and Transportation Model

2.2 The Role of GIS in Transportation Planning Process

Some GIS functions can be incorporated into the transportation planning modeling process to solve the problems inherited in 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 nonspatial data in graphics form,

2. a network topology-generating function to provide the basic node-link scheme and necessary attribute data, and

3. a spatial analyst to perform spatial search and query (such as the routing and allocation of transportation supply centers).

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, GIS may overcome the aggregate nature of transportation planning model structure that ignores spatial variations. Specifically, GIS can manage and manipulate spatially oriented data structures, such as parcel-based data in a study area. In addition, GIS as an output interpreter can summarize large amounts of numerical data into single pictures that "tell a thousand words."

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

The first two roles of GIS to the transportation planning process can be accomplished easily if GIS is coupled with procedural programming language routines written in FORTRAN, as demonstrated in this paper. The third GIS role is the use of unique features within GIS.

In establishing the supportive role of GIS, it is very important to reduce the inherent topological differences between the two systems, especially differences between the GIS topology and transportation network topology. Once the one-to-one mapping of transportation network elements and spatial elements in GIS have been established, it is easy to transfer the data of each system back and forth between the two systems.

3 Integration of A Transportation Planning Model and GIS

Interest in combined-system solutions arises from the assumption that the full-blown integrated information and modeling system incorporating both spatial and nonspatial information systems will provide more efficient and reliable results by overcoming the problems identified earlier.

Coupling the independent systems is a practical solution that complements each system's advantages. The benefits of this strategy are that while each system retains its identity and does what it is designed to do the best, the system also gains the advantages of the cooperation with the partner system. On the other hand, integration results in a new class of combined systems that consist of more than three different individual systems. In this case, the comprehensive system incorporates DBMS (Data Base Management System), GIS, ES, and transportation planning models. Integrated information systems are developed to recognize that each different information system has its own unique ability to solve problems of a specific data type, requiring that an interface be built to facilitate the interchange of different data types among systems.

In the integration of GIS and transportation planning models to solve problems of transportation planning models, data compatibility and communication issues are crucial to facilitating the data transfer among the systems. For example, in classifying a parcel's land-use type, the ES output is a symbolic code assigned to the parcel, which is not directly recognizable by GIS. In a similar way, the GIS database file must be converted to a form that the transportation planning models can use, such as the ASCII[2] format or vice versa.

Patterson (1990) recognizes the linkage gap between GIS and transportation planning models and provides three situations (shown in Figure 1), in which one-to-one correspondence in networks between the two systems is not always possible. Specifically, it is difficult to identify the links in the transportation networks that correspond to particular links in the GIS networks.

As shown in Figure 1, 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 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 is becoming more and more important in the application. If the planner is not in the US, 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. The following section focuses on specific software and will explain more about this topology difference and the conversion process.

[2] ASCII stands for American Standard Code for Information Interchange.

[3] Stands for Topologically Integrated Geographic Encoding and Referencing and Dual Independent Map Encoding.

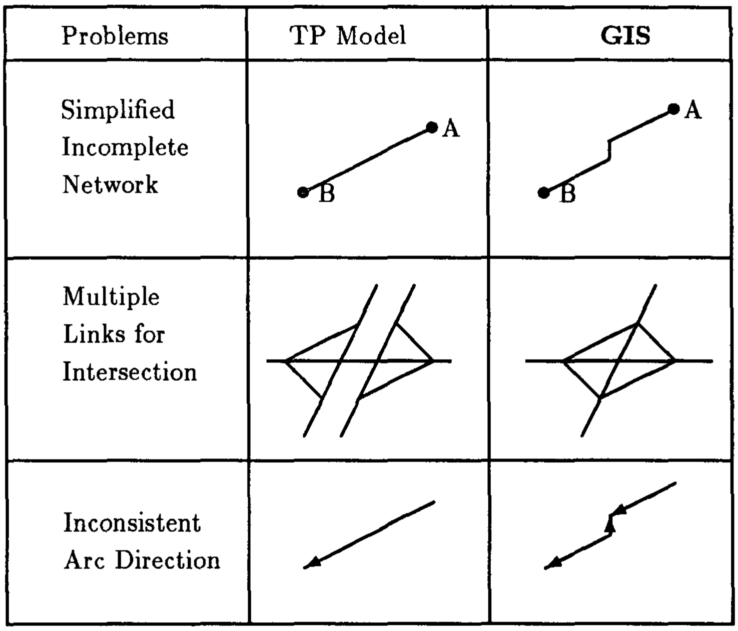

Figure 1: Network Discrepancies Between Transportation Planning Model and GIS (TP model: transportation planning model)

3.1 The Topology of GIS and Transportation Network Data Structure

In this paper, pc ARC/INFO and TRANPLAN have been chosen as GIS software and transportation planning model packages for the discussion of the GIS and transportation model linkage. In order to circumvent the three problems Patterson (1990) identified in the previous section, all physical transportation networks (national roads and expressways) have been digitized using a real map of 1,100,000:1 scale in the proposed case study[4]

Arc-node topology created in ARC/INFO cannot be directly used as a node-link scheme in the TRANPLAN network. The main reasons why arc-node topology is directly incompatible with the node-link scheme are:

1. TRANPLAN requires each zonal node to be numbered from 1 to n (if there are n TAZ's), whereas the intersection nodes can be numbered without such restrictions.

2. There is no distinction between zonal node and intersection node in the GIS topology.

[4]Even though the actual digitizing and topology building are not simple tasks, having a digital version of a map, as a fundamental basis of transportation studies, will be worthwhile if it can aid transportation planning modeling process in an efficient way.

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 and other nodes from $(n+1)$ to m, where m is last node satisfying such relationship as $(n+1) < m$.

Some people may propose that the arc-node topology can be modified to coordinate with the transportation planning model. The nodes generated during the digitization process, however, are not easy to change using commands available in ARC/INFO modules. Furthermore, it is useless to couple GIS and TRANPLAN 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 topology but also to automate the conversion of GIS arc-node topology into the transportation planning model's node-link topology on a real-time basis.

3.2 Topology Conversion Algorithm

The topology conversion algorithm proposed in this paper 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 in transportation planning model). Then it will renumber each zone node and intersection nodes.

As shown in Figure 2, whatever node is connected to a zone centroid (assumed to be chosen before the digitization process) will be selected in Phase I, based on the arc User-ID set bigger than θ, during the digitization process to differentiate plain arc and zonal arc (A zonal arc may be defined in such a way that the User-ID value of the arc exceed θ[5].). 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 TRANPLAN. The converted and rewritten arc-node topology will be the basic input for transportation planning model's network generation module and it will be combined with attribute data such as the capacity and speed of links based on the User-ID value of each arc.

[5] In the case study, θ value of 3000 has been used, since TRANPLAN in DOS (Disk Operating System) version can handle up to 3000 zones.

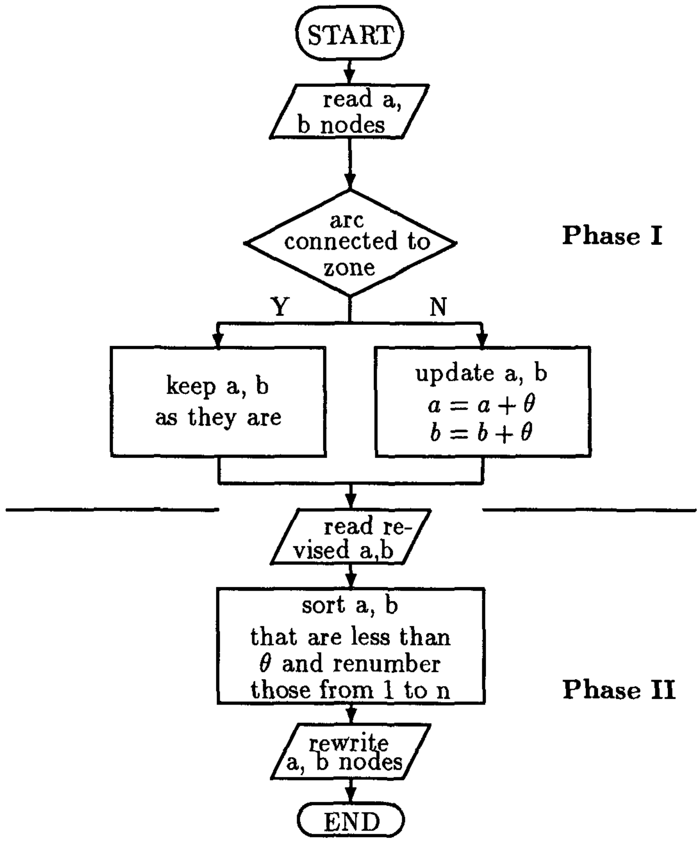

Figure 2: General Flow of the Topology Conversion Algorithm

4 An Example of Integration: TranDASS

TranDASS (**Tr**ansportation planning **D**ecision **A**id **S**upporting **S**ystem) is a combined system integrating transportation planning models and GIS that aims to solve the problems of the conventional transportation planning process identified previously.

4.1 Purpose of TranDASS

TranDASS is a prototype of an integrated transportation system for an interactive and user-friendly desktop transportation planning. The purpose of developing TranDASS is to demonstrate the feasibility of combining GIS with transportation planning models using the algorithm developed to convert ARC/INFO coverage topology into TRANPLAN link-node network topology. TranDASS is an improved transportation planning model by incorporating a feedback mechanism, and providing a user-friendly and menu-driven modeling interface.

4.2 TranDASS: System Components and Structure

TranDASS is constructed based on the DSS concept as shown in Figure 3. The components of TranDASS include data and model bases, GIS, and data conversion routines written in

FORTRAN[6].

GIS provides an important service to the integrated system as a front-end of the model base and database, by generating the appropriate data needed by transportation planning models, and by redisplaying the calculated transportation planning model outputs. The topology conversion routine converts the dumped ASCII format of the ARC/INFO topology into a TRANPLAN link-node topology. The link attribute manager has been set up as an independent system to support the TRANPLAN operation. Thus, two options are possible in TranDASS to manage link attribute data: one allows GIS to manage the whole arc data and to convert it to the TRANPLAN format, the other allows GIS to generate only an arc-node topology for the TRANPLAN node-link scheme, to which all the link attribute data will be combined later. In this paper, the second method was used.

4.3 Typical System Operation

The typical task sequence of TranDASS is shown in Figure 4. TAZ boundary setting module determines efficient sizes and numbers for TAZs. Each zone's socio-economic statistics will be calculated in GIS and the results will be stored in the database for the next trip generation stage. The modified GIS topology, due to the network editing, will be the input to the topology conversion routine which generates new TRANPLAN node-link topology automatically. The link attribute routine, developed using the Clipper database language, can update the link attribute database[7] By joining the location data (nodes and link distances) and attribute data, such as the capacity and speed limit of a road, a file containing the complete link data will be generated. It will be combined together with the TRANPLAN input generated by the ES module. As soon as the TRANPLAN input has been generated, the running of TRANPLAN will follow. After the TRANPLAN session is over, the assigned network volumes will be compared with the actual ground counts and chi-square statistics will be calculated. If the chi-square value is not less than the convergence value specified by the user in ES routine, the whole sequential process (from delineating zone boundaries or changes in link attributes

[6] Even though the expert system (ES) has been incorporated as overall system geverning component, it has been excluded in this paper for more concentrating on GIS coupling into the transportation planning process

[7] There are two reasons for the development of attribute management modules in the TranDASS application. In developing highway or transit networks, the user is required to provide each data entry at specific column positions. For example, the origin node should be typed in between column 1 and column 5, the destination node between 5 to 10, and so on. So, any error in the data entry will generate lots of error messages and will be very cumbersome to locate and correct.

The other reason is to expedite the link data preparation stage. Managing the link attribute data separately and combining it with the converted node-link (location) data is much faster than managing each attribute within GIS.

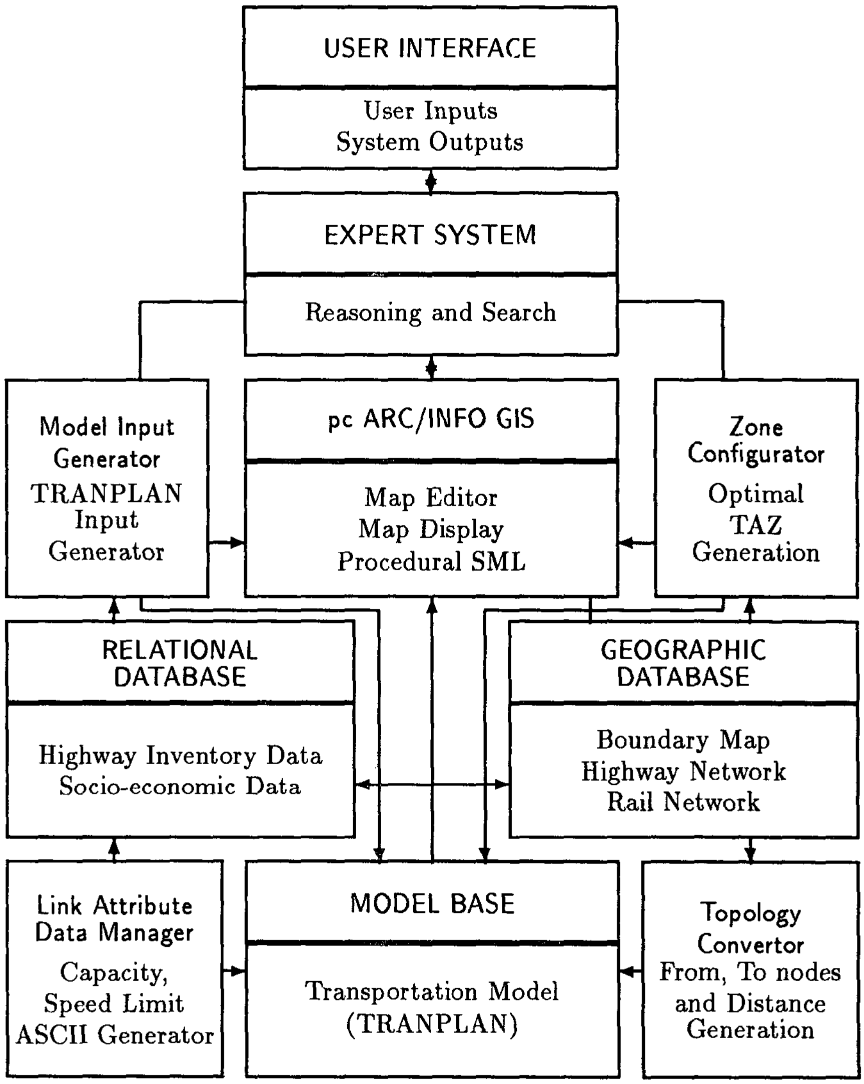

Figure 3: Schematic Structure of TranDASS

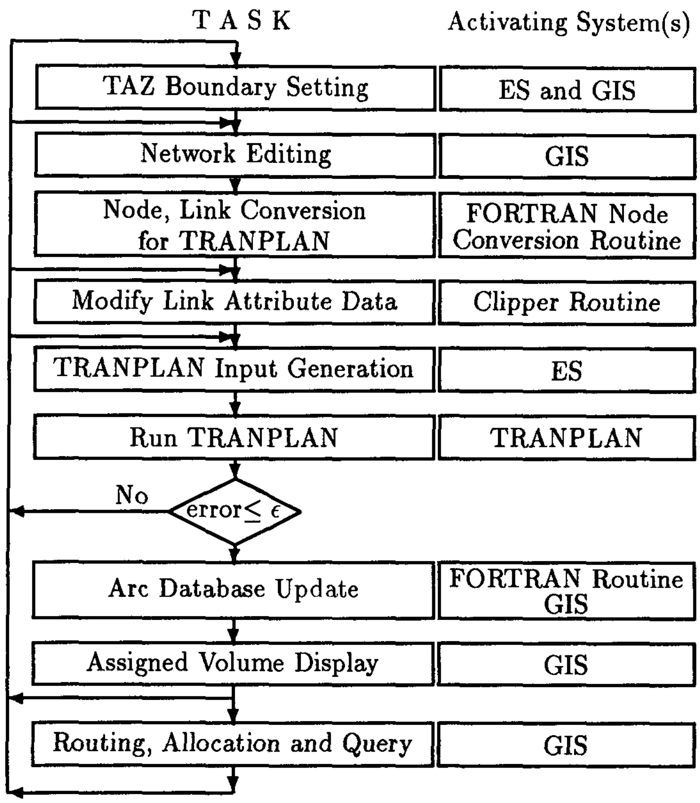

Figure 4: Typical Task Sequence of TranDASS

to assignment) will be executed iteratively until results are satisfactory.

4.4 System Implementation

TranDASS has been implemented using IBM-PC compatible 386 and 486 machines, equipped with a math coprocessor and a color graphics card (at least VGA–Video Graphic Adapter). Executing TranDASS requires pc ARC/INFO 3.4D GIS software, TRANPLAN transportation modeling package and an expert system shell language as its backbone. Interfacing routines for proper data exchange, including the topology conversion algorithm, have been developed using Microsoft FORTRAN. Like the graphics operations, all routines involve extensive calculations and conditional branching. Therefore, faster computers are preferred and some peripherals such as a wide screen and a color printer or plotter are desirable for running TranDASS efficiently.

5 Conclusion and Future Research

In TranDASS, GIS has been adopted as a database integrator, display device for transportation planning model output, and topology generator for direct application to the transportation planning model's network topology through the use of a conversion algorithm. Linking GIS and transportation planning models can not only enhance the user-friendliness and but also partially eliminate other inherent problems associated with labor-intensiveness and no-feedback. It will also save a lot of time by automating the conversion process of the GIS topology to transportation network topology.

From the experience of developing TranDASS, it is believed that the intelligent interface provided by the ES for the modeling tasks can assist planners to employ transportation planning models more easily and effectively. In addition, the interactive, real-time decision support can aid the decision-making activities by quickly generating diverse scenarios and enabling decision-makers to select a better alternative.

The application-oriented approach in this study is quite different from the approach taken by developers of generalized GIS systems, who have applied GIS capabilities to transportation planning[8]. As Matzzie and Rogers (1990) have pointed out, the generalized systems are relatively expensive, require powerful computers, and involve command structures which are not generally familiar to transportation planners. In addition, some drawbacks such as no-feedback still remain unresolved.

In contrast, an application-oriented approach, such as the TranDASS described here, can not only overcome the transportation planning model's theoretical limitations by incorporating the feedback mechanism supported by GIS, ES, and the interface routines written in FORTRAN, but also enhance the effectiveness of the conventional four-step transportation planning process. At the same time, all the important GIS functions can be utilized within the transportation planning framework.

There will be a greater potential for integrating GIS, ES, and the conventional transportation planning models if ES can help GIS handle data more efficiently. However, substantial time and resources will be required to explore this potential fully. Thus, in order to develop a system which can be used in a field-level works (such as planning agencies), substantial time and resources will be required to fully explore this potential. However, improvements in computer software and hardware will likely to continue to increase the potential benefits of making these connections.

[8] The typical example of this type of GIS is TransCAD, in which the conventional four-stage transportation planning process is enabled within GIS.

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